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INCREASED AUTOMOBILE FUEL EFFICIENCY AND SYNTHETIC FUELS

Alternatives For Reducing Oil Imports

Background Paper #3

Environmental Issues of Synthetic Transportation Fuels From Coal

November 1982

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Preface

This volume contains papers written for OTA to assist in preparation of the report *Increased Automobile Fuel Efficiency and Synthetic Fuels: Alternatives for Reducing Oil Imports.* OTA does not endorse these papers. In several instances, the OTA report reaches somewhat different conclusions because of additional information which was obtained later. These papers, however, may prove valuable for readers needing more detailed or specific information than could be accommodated in the final assessment report, and are being made available for such purposes.

ENVIRONMENTAL ISSUES OF SYNTHETIC TRANSPORTATION FUELS FROM COAL

SUMMARY REPORT

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PREFACE AND DISCLAIMER

This Summary Report on Environmental Issues of Synthetic Transportation Fuels from Coal was prepared by an interdisciplinary team of the Science and Public Policy Program, University of Oklahoma, under contract with the Office of Technology Assessment, U.S. Congress. Martha W. Gilliland, Executive Director, Energy Policy Studies, Inc., Omaha, Nebraska, is a subcontractor contributing to the overall report. This summary is based on materials presented in a Background Report which is available separately.

The analyses and conclusions presented in these reports do not necesarily reflect the views of the Office of Technology Assessment or the University of Oklahoma and are the sole responsibility of the authors.

ENVIRONMENTAL ISSUES OF SYNTHETIC TRANSPORTATION FUELS FROM COAL

SUMMARY REPORT

Page

INTRODUCTION 1

1.0 OVERVIEW OF ENVIRONMENTAL CONCERNS 5

1.1 MINING 7

1.2 COAL LIQUEFACTION AND REFINING. 8

Air 9
Trace Organic Compounds 12
Water 13
Solid Wastes. 15
Other Impacts 16

1.3 PRODUCT TRANSPORT AND END-USE 18

2.0 ARE THERE SIGNIFICANT ENVIRONMENTAL DIFFERENCES AMONG THE COAL LIQUEFACTION PROCESSES? 24

2.1 EMISSIONS DURING "ROUTINE" OPERATING CONDITIONS 29

Air Emissions 29
Water Effluents 29

2.2 UPSET/ACCIDENT RISKS. .30

2.3 ENVIRONMENTAL HEALTH RISKS. 33

2.4 PRODUCT AND CONVERSION EFFICIENCY DIFFERENCES 36

2.5 UPGRADING AND REFINING. 42

3.0 WHAT ARE THE IMPORTANT LOCATIONAL FACTORS AFFECTING ENVIRONMENTAL IMPACTS? .46

3.1 COAL CHARACTERISTICS. .46

3.2 REGIONAL DIFFERENCES IN ENVIRONMENTAL IMPACTS 50

Air Resources 55
Water Resources and Aquatic Ecosystems. 55
Terrestrial Ecosystems. 57
Linkages Between Air, Water, and Land Resources: Acid Rain 62
Overall Ecological Characteristics. 64

3.3 LOCAL FACTORS AFFECTING ENVIRONMENTAL IMPACTS 65

4.0 ARE OUR INSTITUTIONAL MECHANISMS ADEQUATE TO ENSURE ENVIRONMENTAL PROTECTION? 71

4.1 MONITORING DIFFICULTIES 72

4.2 ENVIRONMENTAL STANDARDS AND COMPLIANCE INCENTIVES 74

Construction Quality Control. 75
Environmental Standards 76
Industry Concensus Standards. 77

4.3 PUBLIC PERCEPTIONS. 78

4.4 ENVIRONMENTAL RESEARCH PROGRAMS 82

Technical Research Gaps 83
Social and Policy Research Gaps 83
Research Program Organization 85

5.0 WHAT ARE THE ENVIRONMENTAL RISKS OF AN ACCELERATED SYNFUELS COMMERCIALIZATION PROGRAM? 86

5.1 RISKS DUE TO TECHNICAL UNCERTAINTIES. 88

5.2 DIFFICULTIES IN MONITORING. 90

5.3 REGULATORY LAG. 93

5.4 IMPACTS FROM RAPID CONSTRUCTION 94

REFERENCES 97

LIST OF FIGURES

Page

1-1: Coal Liquefaction Alternatives. 3

1-2: Surface Area Requirements for Coal-Strip Mining etc. . . 8

1-3: Range of Air Pollution Emission Levels 10

1-4: Size Ranges of Coal-Fired Power Plants with Emission Equal etc. 11

1-5: Relative CO_2 Emissions from Combustion of Various etc. 23

2-1: Simplified Direct Liquefaction Process-Waste Stream Sources etc. 24

2-2: Simplified Indirect Liquefaction Process-Waste Stream Sources etc. 25

2-3: Comparison of Product Outputs 38

2-4: Range of Product Outputs from the Exxon Donor Solvent Process 39

2-5: Comparison of Conversion Efficiencies 40

3-1: Distribution of Coal Resources in the Coterminous 48 States 48

3-2: Direct Coal Liquefaction Favors Bituminous Coals Due to Hydrogen Requirements for Oxygen Removals 50

5-1: Time Schedule for Two Direct Coal Liquefaction Processes 87

5-2: Synfuel Plant Construction Labor Requirement Near Owensboro, Kentucky 95

5-3: Workforce Schedules for Coal Gasification Projects. . . . 96

LIST OF TABLES

Page

1-1: Selected Environmental Issues for Coal Synfuels. 6
1-2: Summary of Transportation End-Use Problems 20
2-1: EEstimated SO_2 Emissions from the Flare in the SRC II etc. 32
2-2: Efficiency of Refining SRC II Liquids. 44
3-1: Regional Coinditions Affecting Environmental Impacts 51
3-2: Factors Contributing to Regional Environmental Sensitivity to Synthetic Fuel Development 54
3-3: Air Quality Characteristics and Problems 56
3-4: Water Resources and Aquatic Ecosystems: Characteristics and Problems 58
3-5: Annual Pattern of Land Use for Coal Surface Mining Projected in 1985 59
3-6: Terrestrial Ecosystems: Characteristics and Problems 61
3-7: Examples of Potential Contributors to Acid Rain 63
3-8: Local Factors Affecting Environmental Impacts 65
3-9: Survey of Sites Selected for Coal Liquefaction Projects at Advanced Stage 67
3-10: Initial Site Requirements Specified for Coal Liquefaction Demonstration Plangs 68
3-11: Siting Criteria for Coal Conversion Facility 70
4-1: Difficulty in Detecting Environmental Hazards 73
4-2: Range of Public Perceptions of Synthetic Fuels Industry 81
4-3: Selected Technical Information Gaps 84
5-1: Health Risks Potentially Resolved during a Normal Development Schedule 91
5-2: Typical Latency Periods in Cancer Detection 93

ENVIRONMENTAL ISSUES OF SYNTHETIC TRANSPORTATION FUELS FROM COAL

SUMMARY REPORT

INTRODUCTION

Environmental impacts from large-scale commercialization of coal liquefaction are important to government, industry, the public, and a variety of interest groups. This report reviews environmental issues associated with coal liquefaction processes by addressing the following topics:

- A comparison of the environmental differences among technologies;
- A comparison of the impacts among different coal regions;
- A description of the uncertainty of synfuels data and environmental effects; and
- An identification of problems aggravated by accelerated development schedules.

Section 1 summarizes expected environmental impacts from major steps in the liquefaction process--that is, mining, liquefaction, and end-use. The technologies are compared in Section 2, emphasizing how the differences may affect environmental issues. Section 3 identifies impacts affected by locational differences, while Section 4 explores institutional issues. The concluding section (5) discusses environmental risks intensified by rapid commercialization programs.

As indicated in Figure 1-1, after coal is mined, prepared, and shipped to a conversion facility, there are two basic methods of getting liquid fuels from coal--the direct and the indirect routes --both based on chemistry developed in Germany before World War II. The direct way (or hydrogenation method) involves fracturing the complex coal molecules and adding hydrogen to the fragments; the smaller the fragments and the more hydrogen added, the lighter the liquids produced. On the other hand, the indirect method first converts (by incomplete combustion) the coal to a medium-Btu gas, primarily carbon monoxide and hydrogen. After purification, the carbon monoxide and hydrogen are combined catalytically to produce the liquid fuel--either methanol (methyl alcohol) or hydrocarbons, depending upon the catalyst.

Today there are three direct processes in the advanced pilot plant stage:

- Solvent Refined Coal II (SRC II);[1]
- H-Coal; and
- Exxon Donor Solvent (EDS).

They differ mainly in their mechanical features (e.g., reactor design) and in whether or not the hydrogenation is done catalytically. Each requires:

(1) Preparation of a coal slurry--ground coal plus solvent;

(2) Preheating the coal slurry near reactor temperature;

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[1] The SRC I process also is a direct process producing liquid products. Because it has been developed to produce a clean solid fuel and because it is closely related to the SRC-II process, it is not emphasized in this report.

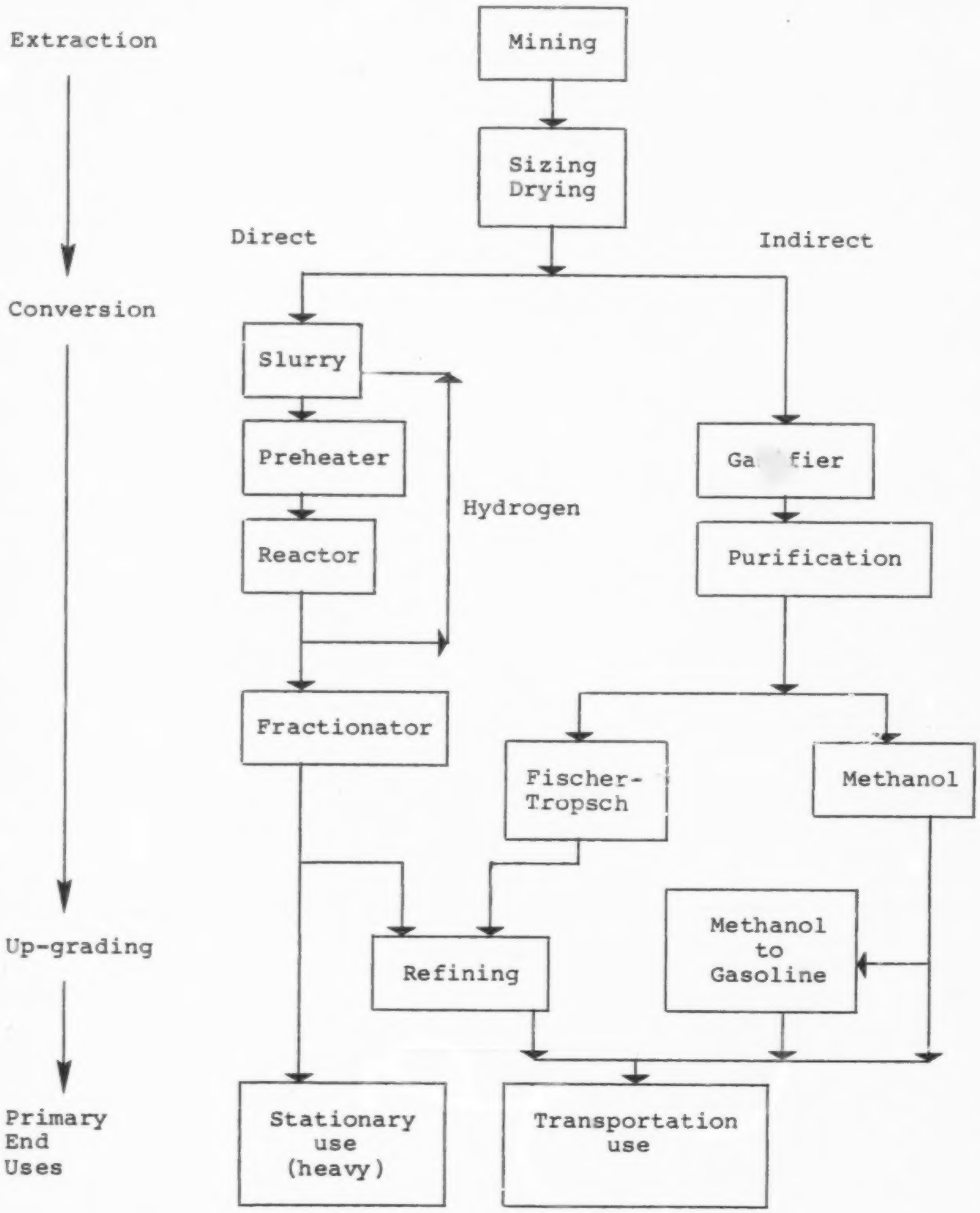
Extraction
Mining
Sizing Drying
Direct
Indirect
Conversion
Slurry
Preheater
Hydrogen
Reactor
Gasifier
Purification
Fractionator
Fischer-Tropsch
Methanol
Up-grading
Refining
Methanol to Gasoline
Primary End Uses
Stationary use (heavy)
Transportation use

Figure 1-1: Coal Liquefaction Process Steps

(3) A liquefaction step in the reactor;

(4) The separation of hydrogen from the reactor effluent in order to recycle hydrogen; and

(5) Distillation of the liquid from Step 4 to provide products, recycle solvent, and an ash-laden liquid slurry.

They differ principally in that SRC II uses no catalyst, H-Coal has catalyst in the liquefaction reactor and EDS partially hydrogenates, catalytically, the recycle solvent in a separate step. Following the separation of the lighter liquids and distillate, the disposition of the heavy "bottoms" (which also contain most of the ash) is a common problem. It can be used as a fuel or, via partial combustion, as a hydrogen source; the choice depends upon the energy balance and economics of specific commercial plant designs.

There are three basic indirect processes for producing transportation fuels from coal:

(1) Methanol;

(2) Mobil's Methanol to Gasoline conversion; and

(3) Fischer-Tropsch.

All indirect processes first gasify coal to produce a synthetic gas --a mixture of carbon monoxide and hydrogen (plus impurities). After purification, the gas is fed to a catalytic converter. One type catalyst will produce methanol and is used commercially today on carbon monoxide/hydrogen mixtures obtained from natural gas (methane). Methanol can be blended with gasoline or, with certain engine modifications, can be used directly as motor fuel. A catalyst developed by Mobil can convert methanol directly into gasoline. The Fischer-Tropsch process employs catalysts that produce a range of primarily light hydrocarbon fuels. The products of both the direct and indirect processes are summarized later in Section 2.

For direct process liquids, considerable upgrading is required to produce stable fuels. Upgrading is minimized if fuels are used in stationary combustion such as for industrial boilers. If transportation fuels, such as gasoline, are desired then refining is required. This refining requires extensive hydrogenation and other steps to meet fuel specifications. The Fischer-Tropsch indirect process produces liquids that also require some upgrading, although to a much lesser degree. The Mobil Methanol-to-Gasoline technology does not require an additional refining step, nor does methanol which in some applications can be blended in small amounts with existing transportation fuels.

1.0 OVERVIEW OF ENVIRONMENTAL CONCERNS

Coal synfuels will produce many environmental problems, some of which are unavoidable while others can be avoided or at least minimized with appropriate designs and management practices. Some environmental problems are similar to those encountered with any large-scale industrial activity, especially those utilizing the nation's coal resources, while others will be relatively unique to coal liquefaction. Generally, problems will vary among regions and the types of coal liquefaction technologies employed. Table 1-1 summarizes major environmental issues associated with producing synthetic fuels from coal, according to the major steps in the

TABLE 1-1: SELECTED ENVIRONMENTAL ISSUES FOR COAL SYNFUELS

Production Stage	Land Use and Water Quality	Air Quality	Ecosystems	Safety and Health	Other
Mining	Short- and long-term land use changes, erosion, and uncertainty of reclamation in arid West Aquifer disturbance and pollution Nonpoint source water pollution (acid mine drainage--East; sedimentation--West) Subsidence	Fugitive dust (especially in the West)	Disruption of wildlife habitat and changed productivity of the land Siltation of streams Habitat fragmentation from primary and secondary population growth	Mining accidents Occupational diseases in underground mining (e.g., black lung)	Increased water use for reclamation Coal transportation impacts on road traffic and noise
Liquefaction and Refining	Potential surface and groundwater pollution from holding ponds Wastewater discharges (East) Disposal of large amounts of solid wastes Local land-use changes Construction on flood plains	Emissions of "criteria pollutants" (i.e., NO_x, SO_2, particulates, etc.) Fugitive emission of carcinogenic substances Possible releases of trace elements Releases during "upset" conditions Possible localized odor problems	Air pollution damage to plants Contributions to acid rain Wildlife habitat fragmentation from population increases Contributions to the "greenhouse" effect	Occupational safety and health risks from accidents and toxic chemicals Carcinogens in direct process intermediates and fuel products	Water availability issues (especially in the West)
Product transport and end-use	Product spills from trains, pipelines, and storage	Changed automotive exhaust emissions (increase in some pollutants, decrease in others) Increased evaporative emissions from methanol fuels Toxic product vaporization	Acute and chronic damages from spills	Exposure to spills Uncertain effects of trace elements and hydrocarbons	Potential change in fuel economy Methanol corrosion and reduction of existing engine longevity

process--coal mining, liquefaction and refining, and the transport and end-use of the product.

1.1 MINING

The impacts from coal mining include:

- Disruption of aquifers, threatening nearby water wells;
- Water pollution caused by runoff from disturbed lands (particularly siltation and acid drainage);
- Losses in land productivity from soil alteration (especially in prime agricultural areas);
- Loss of wildlife habitat;
- Risks to worker health and safety; and
- Subsidence.

Coal liquefaction creates particular concern about mining impacts because of the very large coal requirements; for example, a two million barrel per day (bbl/day) coal synfuel industry would consume roughly 300 million tons of coal per year, an amount equal to 37 percent of the coal produced nationally in 1980. Some projections for coal production for the year 2000 have indicated a level of about 1,500 to 2,000 million tons per year (tpy) (U.S., Congress, OTA 1979). If the synfuel industry achieves a level of production of two million bbl/day, about 15 to 20 percent of U.S. coal mining would be dedicated to coal liquids. Based on projected coal mining patterns (i.e., projected regional distributions and surface vs. underground), over a 30-year period the surface area disturbed by mining at this rate would equal about 850 square miles (see Section 3.2). Figure 1-2 illustrates the regional variation

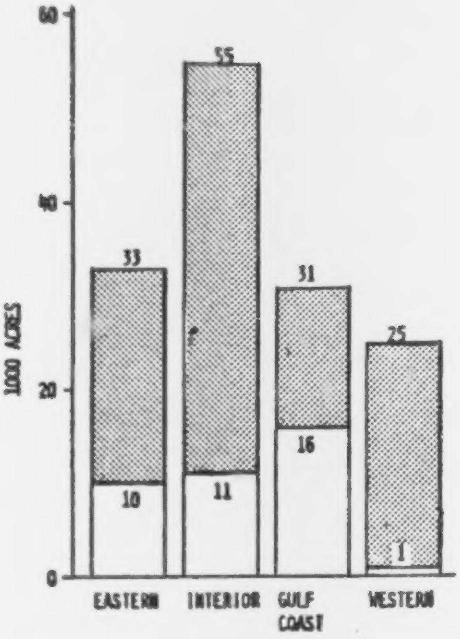

Figure 1-2: Surface area requirements for coal strip-mining over a 30-year lifetime for a 50,000 bbl/day plant.

by showing the coal land requirements over 30 years for a 50,000 bbl/day plant located in four different coal regions. As indicated, the variation can be large, ranging from 1,000 acres in certain western coal fields to 55,000 acres in the least productive Interior region coal fields. These differences are due to a variety of factors, but are a function of variations in the coal seam thickness and energy content of the coals.

1.2 COAL LIQUEFACTION AND REFINING

Table 1-1 also indicates the range of potential environmental impacts created by the coal liquefaction plant itself. Although important technological differences exist among the various coal liquefaction processes (Section 2), there are also many similarities from an environmental standpoint. All plants are designed to transform a solid fuel, high in polluting compounds and mineral matter, into liquid fuels containing low levels of sulfur, nitrogen, trace elements, and other pollutants. In these processes, large volumes of gaseous, liquid, and solid process streams must be continuously and reliably handled and separated into end-products and waste streams. These waste streams, which can be air pollutants, water effluents, or solid wastes, must be treated to meet current laws and regulations that protect environmental values and should be treated to control discharges unique to this technology that are currently unregulated. In addition to these waste streams, other environmental concerns include potential ecosystem disruptions from population increases associated with building and operating the plants, the water requirements for cooling and other process needs, occupational safety and health risks, and possible increased hazards from using the synthetic fuels.

Air

Figure 1-3 shows the range of expected emission levels for selected "criteria pollutants" for liquefaction plants producing 50,000 bbl/day. As a point of comparison, a new coal-power plant meeting existing air emissions standards and capable of utilizing the same rate of coal as a 50,000 bbl/day liquefaction facility (which would have a capacity of about 1,700 to 2,600 megawatts) would produce roughly five to thirty times as much NO_x and

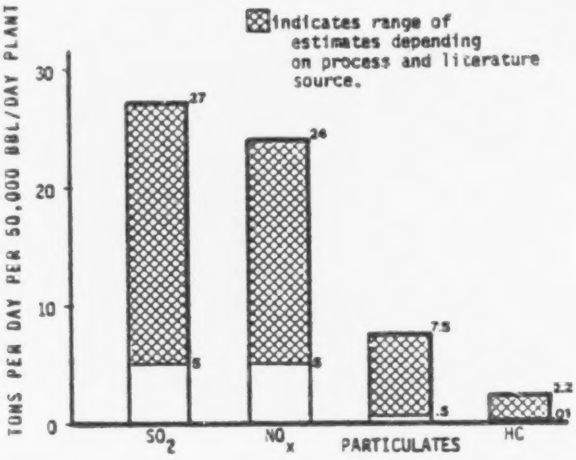

Figure 1-3: Range of air pollution emission levels.

SO_2, and one to twenty times as much particulates.[1] Therefore, while the emissions of criteria pollutants from coal synfuel plants are certainly not insignificant, they are generally much less than what could be expected from a large coal-fired power plant. The size of a coal-fired power plant (with emission rates equal to those described in the preceding footnote) which would give equivalent levels of emissions is shown in Figure 1-4. On the basis of plant size shown in the figure, the coal liquefaction plants are

---

[1] Power plant and liquefaction facility size and emission rates are based on continuous operating conditions. Assumed liquefaction thermal efficiencies range between 45 and 69 percent (see sections 2.4 and 2.5), and power plant efficiency is 35 percent. The standards assumed for the coal-fired power plant (i.e., New Source Performance Standards) are: 0.03, 0.6, and 0.7 pounds per million Btu's of coal burned for particulates, SO_2, and NO_x, respectively. Emission standards are more complex than this, but these emission rates can be considered as "typical" values.

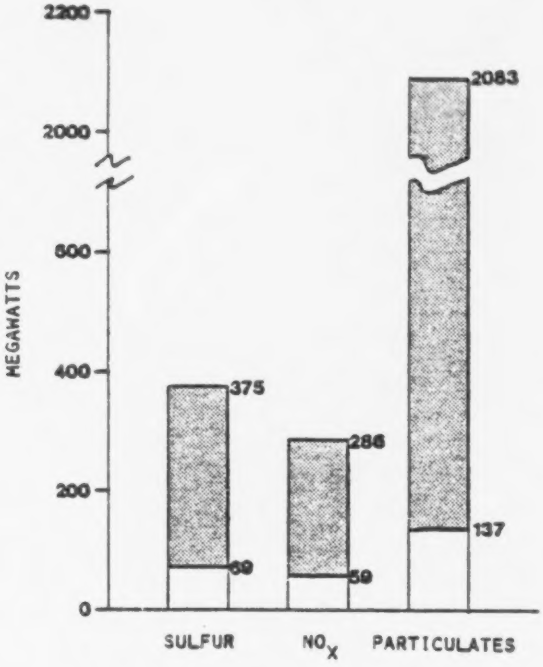

Figure 1-4: Size ranges of coal-fired power plants with emissions equal to 50,000 bbl/day synfuel plants.

equivalent to relatively small power plant units, except for particulates. Air dispersion modeling calculations have, in fact, shown that coal liquefaction facilities should be able to meet even the relatively stringent Prevention of Significant Deterioration (PSD) Class II standards for ambient air quality during "normal" operations in all locations studied.[1] However, it should be emphasized that this general finding is based on emission rates during "normal" operations only; during "upsets" or emergencies the

---

[1] Locations where dispersion modeling has been performed include western, interior, and eastern states (see Background Report). However, if multiple industrial pollution sources desire to locate in an airshed, PSD Class II increments could pose a constraint.

PSD Class II standards do not apply, but emission rates could be considerably higher for relatively brief periods.

Another potential problem is odor, which can be quite important on a localized basis. Odor episodes outside plant boundaries are well documented from petroleum refineries (NAS, 1979). Complaints by residents living near refineries include description of repeated annoyance, and frequent or occasional dizziness, nausea, vomiting, eye irritation, burning and irritation of the nose, and other symptoms (MITRE, 1981). At the present time, information is not available to indicate whether odor problems from coal liquefaction facilities may be better or worse than refineries. Like petroleum refineries, hydrogen sulfide is likely to be one of the major malodorous emissions (MITRE, 1981) because of its relative abundance in process streams. The lowest detection thresholds are for chemicals such as chlorophenols and mercaptans. Emission sources of many of the malodorous chemicals include fugitive emissions from valve fittings and pumps, venting or flaring, waste treatment ponds, and storage ponds. Data on levels of emissions from coal liquefaction facilities for specific malodorous compounds are not available.

Trace Organic Compounds

Trace emissions of carcinogenic compounds formed in the liquefaction process are probably of more concern than criteria pollutants. Some coal liquefaction processes (primarily those of the "direct" type) produce a wide range of organic compounds including polynuclear aromatic hydrocarbons and polynuclear aromatic amines known to be carcinogenic. The concern is that workers and the general public could be exposed to these substances through trace levels in pollution streams, through accidental releases to the air and water, and through direct contact with end-products which might contain these compounds. At the present time, the degree of risk is highly uncertain due to:

- Lack of information on the precise nature of the chemical compounds produced;
- Uncertainty about the ability to control releases;
- Potential for multiple exposure paths for the populace;
- Inadequate scientific understanding of the long term human health effects from low-level but chronic exposures; and
- Potential for detoxifying the end products.

These uncertainties are primarily related to the absence of commercial plant experience and the limited environmental health testing of intermediate and end products.

Because of these human health concerns, detoxification or segregation of these streams with on-site use and disposal or special transportation methods may emerge as an essential prerequisite to a direct process liquefaction industry. For example, operation of plants to maximize the naphtha fractions (gasoline blending stocks) could eliminate the export of hazardous heavy fractions since these would be used on-site for hydrogen and/or power production (see also, sections 2.4 and 2.5).

Water

Coal liquefaction plants will also produce a number of wastewater streams which contain many pollutants known to cause health and environmental problems. For example, process wastewaters will contain phenol, ammonia, polynuclear aromatic hydrocarbons, chlorides, sulfates, cyanides, and a variety of trace elements such as arsenic, cadmium, and mercury. Existing industrial wastewater treatment technologies are expected to be able to control most of these effluents. However, three factors contribute to the potential for water pollution. First, there is the possibility for incidents that will cause the wastewater treatment systems to not meet design specifications. For example, violations of discharge permit standards apparently occur in the range of between about one and six times per year for a refinery (U.S., EPA, Research Triangle Park 1981).[1] Second, it is still not certain that planned wastewater treatment technologies can continuously control the trace elements and toxic organic compounds or the potential interactions among the various pollutants associated with coal liquefaction processes. Finally, designers are planning on "zero discharge" in the West through the use of evaporative holding ponds, but in the East, plans now call for continuous or intermittent discharge of pollutants.[1] Options that avoid direct discharge have been reviewed for pioneer plants including deep well injection, surface impoundment, brine concentration, water reuse, evaporation, and incineration of residues. However, even where plans call for low or zero discharge rates to surface streams, there are risks due to windblown drift, seepage, spills, or flooding of holding ponds.

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[1] Violations are recorded primarily for discharges of total suspended solids, biochemical oxygen demand (BOD) or pH, not for trace elements, organics, or phenols (U.S., EPA, Research Triangle Park 1981). Refineries operated by major oil companies generally have fewer violations than small independent refineries. In addition, because refineries now employ Best Practicable Control Technology Currently Available, problems with compliance with discharge permit standards have been significantly reduced during the past several years (U.S., EPA, Research Triangle Park 1981). Well managed treatment plants rarely have problems with compliance (Franzen 1981), while poorly managed facilities have recurrent violations (U.S., EPA, NEIC 1981).

Solid Wastes

The disposal of solid wastes also represents an important issue, both in terms of its long-term land-use effects and in terms of the possibility of toxic materials being leached from the disposal site. Despite a wide variation in the composition of these solid wastes, they are basically of two types:

- Large volumes of ash wastes that were originally part of the coal; and
- Elements separated from ash and coal, wastewater treatment sludges, other added materials (such as catalysts) and partial combustion products.

The magnitude of the wastes (largely ash) is great--a 50,000 bbl/day plant over 30 years would produce enough ash to require one square mile of land with waste piled 50 feet high. One of the major issues has to do with whether these wastes (or some portions thereof) should be declared "hazardous" under the 1976 Resource Conservation and Recovery Act and, thus, be subject to very stringent disposal requirements. If this were to occur, it could have serious economic consequences for a synfuels industry.

---

[1] In Eastern locations discharge volumes may represent up to one-fourth of water withdrawn for process or cooling purposes. For example, average discharge for the 6,000 tons per day (tpd) coal capacity SRC-II pilot plant is expected to be 1,238 gallons per minute, and withdrawals are to be 4,826 gallons per minute.

Other Impacts

A range of other environmental problems in addition to those related directly to gaseous, liquid, and solid wastes is important. For example:

- The extremely large plant size--requiring approximately 2,000 acres for a 50,000 bbl/day facility--creates aesthetic and land-use impacts;
- Large shipments of coal to plants located away from mines--for a 50,000 bbl/day plant, roughly 20,000 tons per day, or 200 train cars carrying 100 tons each--create noise, dust, and disruptions to local road traffic; and
- The consumption of water for plant operations--anywhere from 3,400 to 5,900 acre-feet per year (AFY) for a 50,000 bbl/day facility, depending on the design--although only a small fraction of existing supplies in most areas, raises concerns over the appropriate use of an increasingly scarce resource, especially in the arid West.

The process of upgrading and refining the products of coal liquefaction (when required) could occur in on-site refining operations or at a separate refinery. Refineries processing coal liquids need a large capacity for hydrotreating and hydrocracking capability to break down and improve the quality of coal liquids. Many of the wastewater treatment and air quality problems described above for the liquefaction process will be similar for refineries. However, downstream refining problems are likely to be less critical than coal liquefaction steps due to the following features:

- Nearly all of the entrained solids have been eliminated from the product streams. This reduces air, water, and solid waste disposal requirements;

- The sulfur and nitrogen have been largely removed; and
- Most of the trace elements have been removed.

However, compared to existing refineries with crude oil feedstocks, refineries processing coal liquids face additional problems:

- The heavy liquids from coal are not compatible with the heavy ends of crude oil, and therefore would have to be refined in separate units;
- From direct coal liquefaction processes, some entrained particulate matter containing trace elements remains;
- Heavy coal liquids fractions will contain polynuclear aromatic hydrocarbons and polynuclear aromatic amines that need to be segregated and hydrotreated to reduce their toxicity;
- More severe hydrotreatment capacity is needed, and special wastewater treatment capacity and capability may be needed;
- Although much of the sulfur and nitrogen may be removed, levels may exceed those normally found in petroleum feedstocks (especially for nitrogen); and
- Coal liquids are unstable compared to petroleum feedstocks, requiring short distance transport and timely utilization of feedstocks (Conser, Garrett and Weiszmann 1979).

No data are available on the air, water, and solid waste discharges anticipated from a coal liquids refinery. This may mark a significant omission in the Department of Energy (DOE) and Environmental Protection Agency (EPA) programs for characterizing advanced fossil fuel programs. Coal liquids are being tested in existing refineries, but a large-scale coal liquids-refining operation would most likely require a grass roots refining facility, probably in close proximity to the coal liquefaction plant, in order to utilize the unstable coal liquefaction products (Conser, Garrett and Weiszmann 1979).

1.3 PRODUCT TRANSPORT AND END-USE

As with crude oil and existing transportation fuels, the transport of coal liquefaction intermediate and final products will be by pipe, rail, truck, and barge. Environmental impacts can result from spills, fires, and explosions. The nature of most transportation impacts from shipping coal liquids is similar to those for shipping crude oil, now a wide-spread activity. However, two differences stand out: the toxicity of intermediate products from direct processes is higher than for petroleum, which may result in a greater environmental risk and may require special clean-up precautions to avoid contamination of workers; and coal liquid feedstocks may plug or reduce pipeline performance. For these reasons, special precautions in shipping direct process intermediate products may be appropriate. For example, transportation systems may need to employ insulated pipe or heated containers (U.S., DOE 1981a).

Some coal liquefaction products will be shipped relatively short distances (less than 100 miles) to nearby refineries, while others will be shipped much longer distances by rail, truck, or pipeline. However, due to product instability and gum formation for direct process coal liquids, long distance pipeline shipment of some products may be restricted primarily to batch bulk shipments, such as tank-cars. For example, fuel oil fractions from the SRC II demonstration facility (6,000 tpd of coal feed) are expected to be shipped by rail. Each month the demonstration plant would use about 12 unit trains, each containing 63,000 tons, for shipping the fuel oil. Based on extrapolation from spills of hazardous commodities, a "reportable" spill[1] would be expected to occur every 1.3 to 2.8 months. Spills over bodies of water would be expected to occur once every 30 to 60 months (U.S., DOE 1981a). Based on volume of a product shipped, a commercial-scale plant would have about 5 times higher probability of spills than would the demonstration plant. Because the transport of products is essential to the coal liquefaction fuel cycle, measures to minimize frequent spills along transportation corridors should be considered an integral part of the safety and hygiene provisions for this technology.

The impacts from end-use of synthetic fuels, compared to those from conventional fuels, depend on the type and uses of fuels produced (ranging from heavy oils to be used in industrial and utility boilers to methanol to be used in automobiles) and the degree of refining used to upgrade the synfuel products. Table 1-2 summarizes the problems associated with the transportation uses of the various fuel forms as compared to petroleum derived liquids.

Differences in environmental effects from alternative fuels end-use are primarily a function of combustion products. However, concern over fuel handling and the effects on engines and their performance may also have secondary environmental consequences.

Emissions are primarily dependent on the quality of fuels and how they are utilized. Direct processes produce fuels which are generally high in aromatic compounds, sulfur, and nitrogen

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[1] A "reportable" spill is one for which losses in value or to property exceed $2,900 (U.S., DOE 1981a).

TABLE I-2: SUMMARY OF TRANSPORTATION END USE PROBLEMS

Coal Derived Transportation Fuel	Combustion Characteristics	Emissions	Engine Effects	Sources
Gasoline from direct processes	Similar to gasoline Blending agent (can improve octane)	NO_x higher Trace elements higher		Epperly, Plumlee and Wade 1980; Simbeck, Dickenson and Moll 1980.
Diesel[a] fuel (from direct processes)	Aromatic fuels smoke Low cetane number (depends on hydrotreating)	Particulates much higher NO_x and hydrocarbons higher potentially (depends on hydrotreating)	Possibly reduced mileage with lower cetane numbers	Ghassemi and Iyer 1981.
Jet fuel (from direct processes)	Aromatic fuels smoke, incomplete combustion	Particulates and hydrocarbons higher	Burnt combustors	Delaney and Lander 1980.
Gasoline (from indirect processes)	Similar to gasoline	Similar to gasoline	Similar to gasoline	Kam 1980.
Methanol	Similar to gasoline when blended in small porportions Uncertain stability	Increased evaporative emissions but possible reduction in exhaust emissions (except aldehydes)	Corrosion	Kermode, Nicholson and Jones 1979; U.S., DOE 1978; Barr and Parker 1976.

[a] Performance of diesel fuels derived from direct process depends in part on the extent of hydrotreating. With severe hydrotreatment, a minimum cetane number of 40 can be achieved (Sullivan et al. 1980).

compared to indirect processes or to petroleum derived fuels.[1] Diesel and jet fuels must be low in aromatic content to avoid incomplete combustion and smoking. In contrast lightweight aromatic compounds are good gasoline feedstocks. For this reason the naphtha fractions of synthetic coal liquids provide a good blending stock and actually can improve the octane rating and performance of gasoline engines. With extensive refining, including severe hydrotreating and hydrocracking, fuels that meet diesel and jet specifications can also be made. Oxygen and nitrogen present in small amounts in direct process components also contribute to product instability. More studies are needed to completely evaluate the storage and long-term performance of liquid fuels derived from direct processes.

Indirect process liquids typically have no sulfur, nitrogen, or particulates. Gasoline from the Lurgi Sasol plant has a low octane rating, but can be upgraded to premium specifications. The Mobil Methanol-to-Gasoline process directly produces a premium grade gasoline. Methanol can be used as is or blended, and generally has lower emissions compared to gasoline, except for aldehydes. Aldehydes can contribute to the formation of photochemical oxidants. A major benefit of methanol is lower NO_x emissions resulting from lower flame temperatures.

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[1] Most crude oils, compared to direct process liquids, are lower in aromatic compounds. However, crude oils have a wide range of compositions in sulfur, nitrogen, and aromatic content. Many U.S. refineries are being modified to accept poorer quality crude oils.

However, the overall and long term performance of engines utilizing these alternative fuels is uncertain. Methanol is relatively corrosive and can reduce engine life. In addition, the instability of fuels and their tendency to form deposits and gums may reduce engine performance and contribute to exhaust emissions. The quality of fuels, however, is largely amenable to modification, so that one major variable affecting performance is the cost and efficiency of refining to provide a suitable grade of fuel. The efficiency of refining is discussed in Section 2.5 which compares the refined products in more detail.

One important issue concerning end-use and the entire synfuel cycle is the global CO_2 problem (i.e., the "greenhouse" effect) and the relative effects that a synfuel program could have. Figure 1-5 shows the contributions to CO_2 emission rates relative to crude oil (this includes CO_2 emissions at both the conversion/processing stages and the end-use stage). As indicated, the production and use of coal synfuels will release approximately 1.7 times more CO_2 than crude oil over the entire fuel cycle. One major study concluded that because synfuels will represent a relatively small contribution to worldwide energy supplies, "CO_2 emissions do not appear to be a major environmental constraint in the development of a U.S. synthetic fuels program" (U.S., DOE, Asst. Sec. for Environment, Off. of Technology Impacts 1980, p. 5-32). However, if CO_2 is perceived to be a major environmental problem in the future, then even the relatively small CO_2 contribution from synfuel plants will need to be considered in the context of other contributing

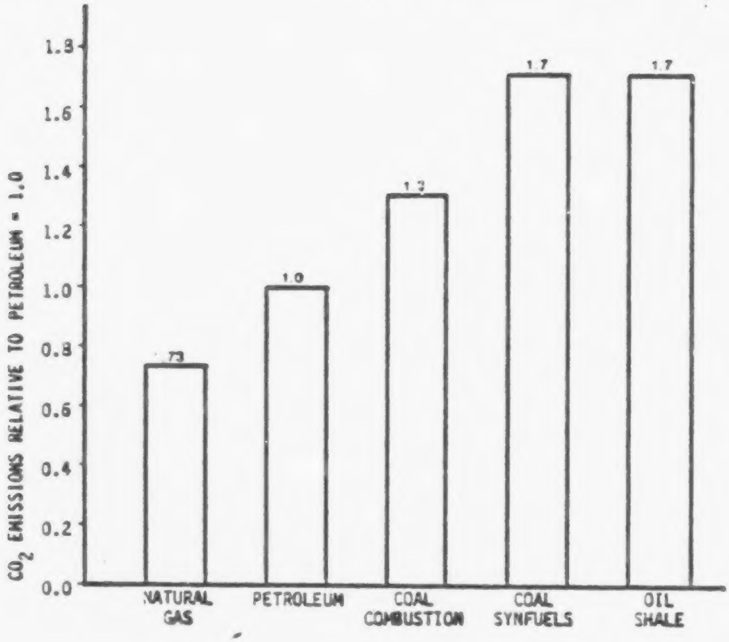

Figure 1-5: Relative CO$_2$ emissions from combustion of various fuel sources.

Source: U.S., DOE, Asst. Sec. for Environment, Off. of Technology Impacts 1980, p. 5-32.

factors (e.g., coal combustion and deforestation) and mitigating measures (e.g., substitution of nuclear power and energy conservation).

2.0 ARE THERE SIGNIFICANT ENVIRONMENTAL DIFFERENCES AMONG THE COAL LIQUEFACTION PROCESSES?

This section summarizes the variations in environmental impact that are related primarily to differences among coal liquefaction processes. Figures 2-1 and 2-2 are simplified diagrams showing effluent streams which must be dealt with in direct and indirect

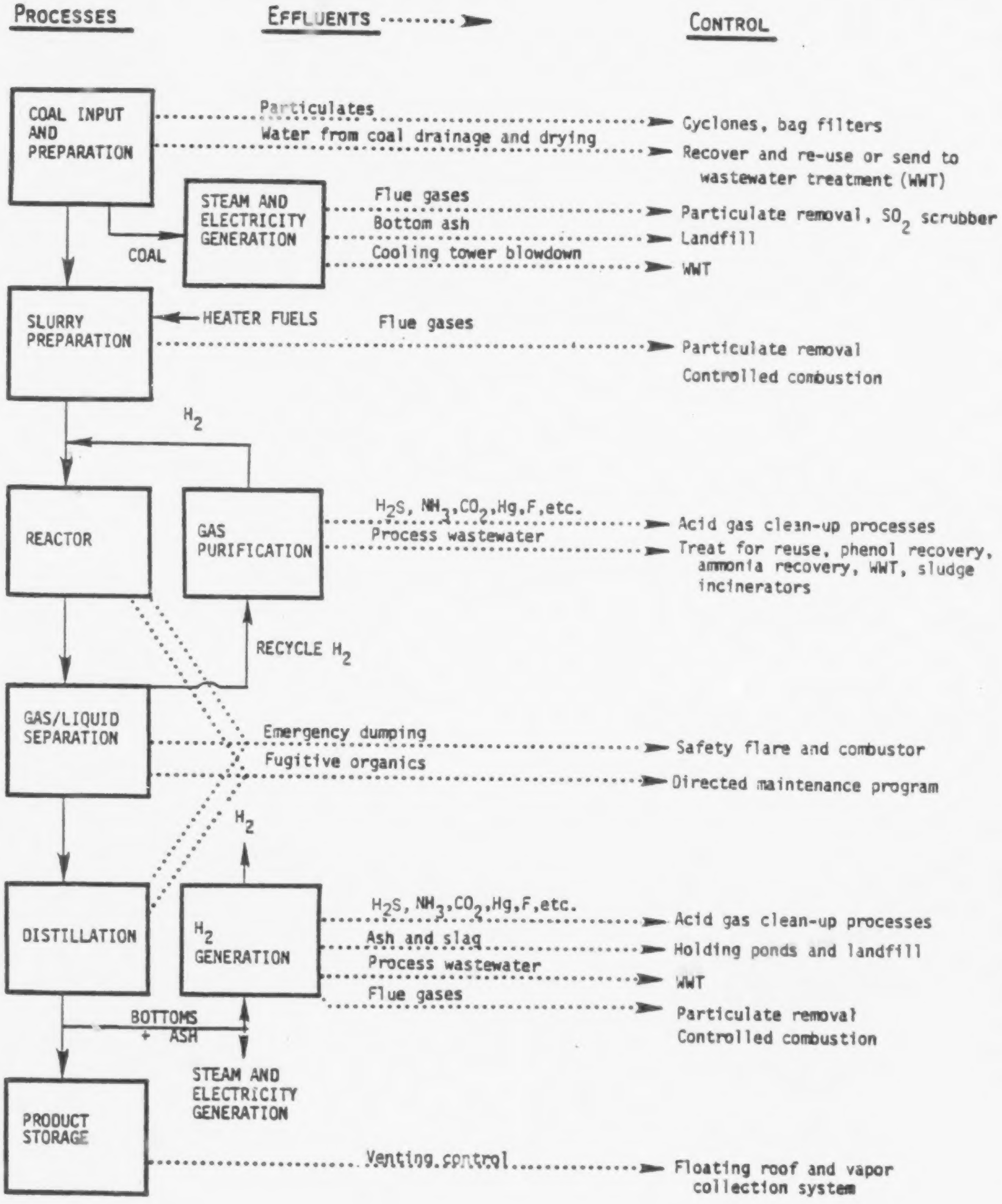
PROCESSES
EFFLUENTS
CONTROL
COAL INPUT AND PREPARATION
Particulates
Cyclones, bag filters
Water from coal drainage and drying
Recover and re-use or send to wastewater treatment (WWT)
COAL
STEAM AND ELECTRICITY GENERATION
Flue gases
Particulate removal, SO_2 scrubber
Bottom ash
Landfill
Cooling tower blowdown
WWT
SLURRY PREPARATION
HEATER FUELS
Flue gases
Particulate removal
Controlled combustion
H_2
REACTOR
GAS PURIFICATION
H_2S, NH_3, CO_2, Hg, F, etc.
Acid gas clean-up processes
Process wastewater
Treat for reuse, phenol recovery, ammonia recovery, WWT, sludge incinerators
RECYCLE H_2
GAS/LIQUID SEPARATION
Emergency dumping
Safety flare and combustor
Fugitive organics
Directed maintenance program
H_2
DISTILLATION
H_2 GENERATION
H_2S, NH_3, CO_2, Hg, F, etc.
Acid gas clean-up processes
Ash and slag
Holding ponds and landfill
Process wastewater
WWT
Flue gases
Particulate removal
Controlled combustion
BOTTOMS + ASH
STEAM AND ELECTRICITY GENERATION
PRODUCT STORAGE
Venting control
Floating roof and vapor collection system

Figure 2-1: Simplified Direct Liquefaction Process-waste Stream Sources and Control

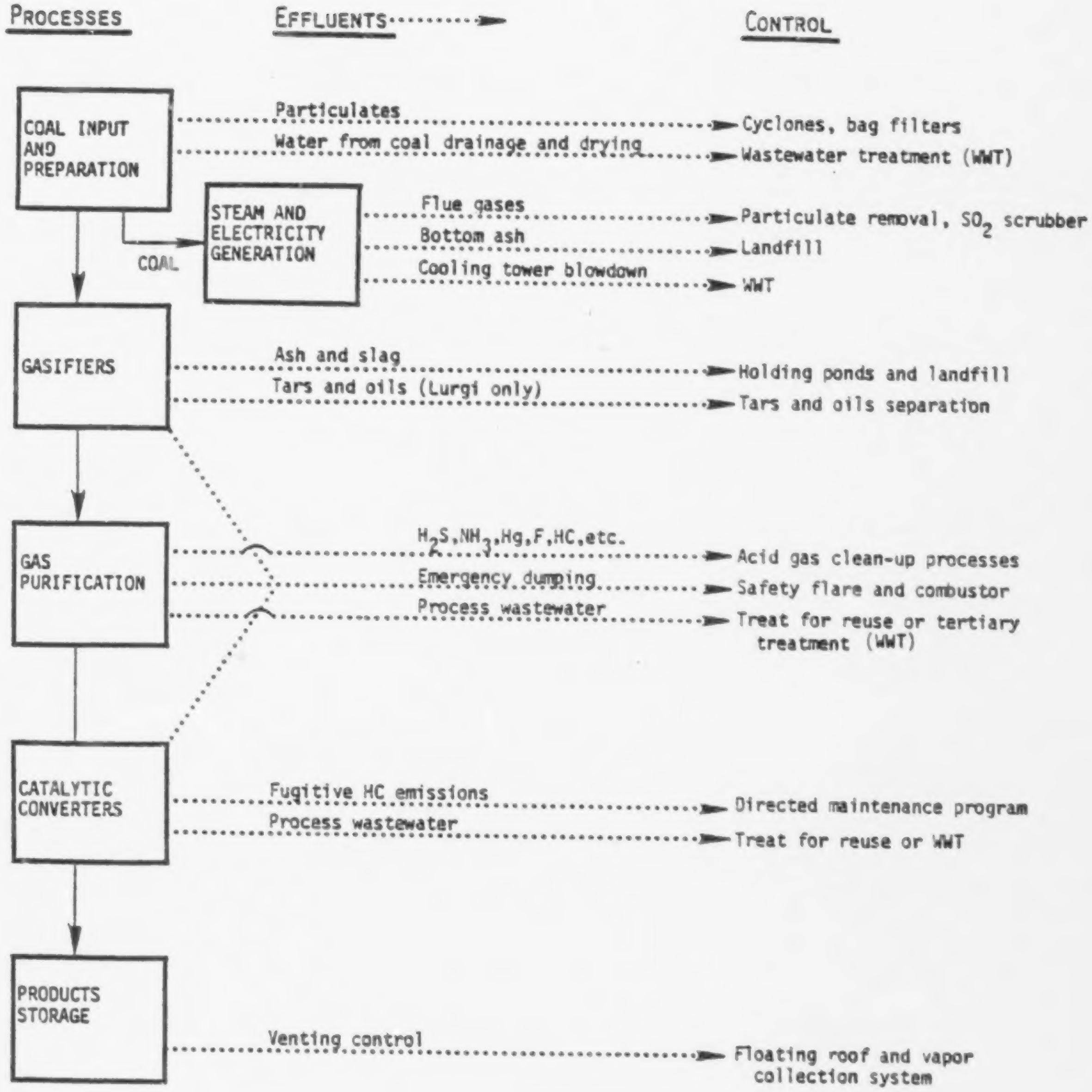
PROCESSES
EFFLUENTS
CONTROL
COAL INPUT AND PREPARATION
Particulates
Cyclones, bag filters
Water from coal drainage and drying
Wastewater treatment (WWT)
STEAM AND ELECTRICITY GENERATION
COAL
Flue gases
Particulate removal, SO2 scrubber
Bottom ash
Landfill
Cooling tower blowdown
WWT
GASIFIERS
Ash and slag
Holding ponds and landfill
Tars and oils (Lurgi only)
Tars and oils separation
GAS PURIFICATION
H2S,NH3,Hg,F,HC,etc.
Acid gas clean-up processes
Emergency dumping
Safety flare and combustor
Process wastewater
Treat for reuse or tertiary treatment (WWT)
CATALYTIC CONVERTERS
Fugitive HC emissions
Directed maintenance program
Process wastewater
Treat for reuse or WWT
PRODUCTS STORAGE
Venting control
Floating roof and vapor collection system

Figure 2-2: Simplified Indirect Liquefaction Process-waste Stream Sources and Control

processes, respectively. While there are significant control process stream differences between the direct and indirect plants, both routes to liquid fuels must deal with the sulfur, nitrogen, and mineral matter in the coal feed. Potentially toxic hydrocarbons and deleterious oxygenated chemicals generated during processing which enter the gas or liquid effluent streams must also be controlled.

As indicated in the following subsection, important differences can be identified between the two major types of liquefaction technologies, direct and indirect. However, several factors complicate the comparison of technologies based on existing data, as described below:

(1) The environmental controls being planned for synthetic fuel plants are primarily based on utilizing technologies from the petroleum, utility, and similar industries, but (a) at present the designs are not final, and (b) there are important differences from this past experience. For example, the wastewater effluents from pilot plants have generally not been sent through a complete environmental control system such as those anticipated for commercial units. The waste streams of some plants have only been subjected to laboratory and bench-scale clean-up tests. Based on past experience, developers expect that extrapolation from bench-scale tests to commercial operations will not produce significant deviations.

However, several important differences can be found in coal liquefaction compared to previous refinery and petrochemical experience.

- Larger levels of trace elements emissions are involved; the fate and controls for emissions have not been determined, especially for direct processes;

- The problem of handling liquid streams containing large amounts of solids (mainly coal ash) presents mechanical design and operational difficulties because of pipe and valve erosion and the potential for flow blockage. This is primarily the case for direct processes (e.g., major problems of this type were encountered in the H-coal pilot plant);

- Large quantities of reduced sulfur compounds are produced which require handling; and

- The existence of large complex aromatic compounds in coal liquefaction process streams and end-products (especially for direct processes), some of which are known carcinogens, presents relatively unique problems. The coal tar industry has experience with such compounds, but under very different circumstances.

(2) Direct comparison of emission levels and control costs between different liquefaction processes is difficult because the bases and premises of the plant designs differ from one developer to another. As an example, the sulfur concentration in the coal feed is important. If a sulfur recovery system is designed to collect 99.8 percent of the sulfur, the effluent will have total sulfur emissions directly proportional to the sulfur in the coal; i.e, 5 percent sulfur coal will release 5 times more sulfur than a one percent feed. Costs may differ because of plans based on different choices of process steps (e.g., selection based on reputed higher reliability levels but at lower control levels). All these types of decisions are bound up in commercial plant designs so that the only valid comparisons between processes would be from designs which used the same bases for the different processes. Without that commonality, cross-comparisons can be highly misleading.

(3) Finally, although synfuel plants will be regulated under a large number of state and federal environmental laws, emission control standards are not yet developed. Plants are currently being designed with environmental controls that developers believe are adequate to obtain the necessary permits. At the same time, EPA and DOE are drafting Pollution Control Guidance Documents (PCGD's) which will provide recommended "guidelines" for the liquefaction technology prior to commercialization. These PCGD's are not legally binding for industry but are advisory for permitting and environmental impact statement review officials.

Given these three areas of uncertainty, analyses of environmental differences among processes must be made with caution. For example, although the literature may report different air emission levels for two different processes, these differences may not necessarily reflect basic differences in the processes. Rather, they might result from different assumptions about the controls applied or the coal characteristics, and from different methods of analysis. The following sections address whether or not differences exist among process types in the following categories:

- Air and water pollution levels under "routine" operating conditions;
- Potential accidents or "upset" conditions;
- Health risks; and
- Conversion efficiency and end-products.

2.1 EMISSIONS DURING "ROUTINE" OPERATING CONDITIONS

Air Emissions

Figure 1-3 given earlier shows the range, across five liquefaction processes (both direct and indirect) of emission levels of selected pollutants under normal operating conditions. The ranges in the data can be attributed to four factors:

- The different processes considered;
- Different sources for the data;
- Different assumptions about controls applied; and
- Calculations based on differing coal types (i.e., heat, ash, and sulfur content).

Despite these uncertainties, there do not appear to be major differences between the levels of "criteria" air pollutants emitted by the various processes under normal operating conditions. This conclusion reflects the fact that for all processes, the majority of gaseous emissions are produced in the auxiliary parts of the liquefaction system (i.e., coal handling, furnaces, boilers, acid gas treatment systems, etc.). These emission sources can all be handled by similar control techniques regardless of the process. The more important variables are coal type and the fuel used for auxiliary energy production (e.g., electric power production). In sum, it is not currently possible to distinguish among the technologies for these variables.

Water Effluents

For similar reasons there is also uncertainty about differences in wastewater pollution levels; in fact, the data on liquid effluent levels is subject to even greater uncertainty than for air emissions. In its preliminary analysis of wastewater treatment for indirect processes, EPA concluded that water pollution control has been "neglected" in synthetic fuel analyses, producing large data gaps and an immediate need for demonstration of the technical and economic viability of effluent controls (*Inside EPA*, 1980). *Despite the uncertainties, important differences exist between direct and Lurgi indirect processes on the one hand and the remaining indirect processes on the other*. These differences are due primarily to the fact that wastewater treatment for direct processes and the Lurgi indirect processes, unlike the others, require phenol separation and the handling of large quantities of complex organic compounds which are produced from the initial coal reactions. For these processes, estimated capital costs for wastewater treatment systems represents about 3 to 5 percent of total plant investment. In contrast, indirect processes based on Koppers-Totzek or Texaco gasification have expected capital costs for wastewater treatment of about two percent, or less, of total plant investment (U.S., EPA, Research Triangle Park 1981).

2.2 UPSET/ACCIDENT RISKS

In many cases of environmental analysis of synfuel plants, the pollution rates and subsequent impact analyses are based on levels that occur during "routine" or "normal" operating conditions. However, of equal environmental concern are the impacts caused by accidents or "upset" conditions.

When process upsets or emergencies occur, such as the blockage of a flow line, they will require the immediate venting of gases to relieve internal pressures and to prevent accidents. This venting will be done through a controlled combustor/flare system typically used in chemical and petrochemical plants. When this happens, normal pollution control systems are by-passed leading to higher emission rates of particulates, SO_2, unburned hydrocarbons, and other pollutants. To illustrate, Table 2-1 shows estimated SO_2 emission rates for the SRC II demonstration plant under upset conditions. A single occurrence of Case B would emit as much SO_2 in 2 hours as normally occurs during 4 to 10 days of operation.[1] Depending on how often they occur, such upsets could account for significant proportions of total emissions. And, the environmental impacts of such peak loadings could be greater than those occurring under normal conditions, although this question is seldom addressed in environmental studies. In the case of the SRC II demonstration plant, the flare stack will be about 235 feet high and in some events will emit a flame 100 feet wide and over 600 feet long.[2] Although the vent/flare system is designed to perform under these circumstances, if plants are located close to urban areas some psychological and aesthetic concerns may be raised.

Accidents and upsets affecting the wastewater treatment system can also occur; for example, surges of toxic compounds could kill

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[1] In some cases if incomplete combustion in the vent/flare system occurs, H_2S and hydrocarbons may also be released.

[2] The flare stack is only used when the rate of venting cannot be handled by the controlled combustor.

TABLE 2-1: ESTIMATED SO_2 EMISSIONS FROM THE FLARE IN THE SRC II DEMONSTRATION PLANT DURING UPSET CONDITIONS

Case	Event Description	Duration (hours)	SO_2 Emissions (tons)
A	One coal dissolver blown down from normal operating pressure to near atmospheric pressure in 45 minutes.	3/4	1
B	Two gasifiers vented at full load upstream of purification.	2	12.9
C	One load dissolver at full rate without purification.	4	5.6
D	Two gasifiers at full rate and pressure. Blocked in and blown down in 5 minutes, bypassing purification.	1/12	.03

Source: Adapted from U.S., DOE 1980, p. C-57.

the organisms in biological treatment systems. Unless adequate capacity exists in wastewater holding ponds, such events could lead to the direct discharge of toxic effluents into surface streams.

Since no commercial size liquefaction plants have operated in the United States, there are no data to measure the frequency of upsets.[1] However, based on comparisons between direct, indirect, and petroleum refining processes, inferences can be drawn on relative frequencies. The greater complexity of the direct processes vis-a-vis the indirect routes suggests that the former would encounter more frequent upsets. Similarly, direct process units, although similar to many refinery steps, would have greater frequency of upsets because of the high level of solids present in many of the streams.[1] Those solids may cause plugging and erosion which would not be encountered in refinery processing. There is a large economic incentive to minimize such upsets because reduced plant on-stream-time dramatically lowers the return on investment. Commercial plant constructors and operators would make use of all in-formation to maintain high on-stream-times.

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[1] Demonstration and pioneer commercial plants which involve scale-up risk, since their design is based on pilot plant information, can be expected to have more frequent upsets than future commercial plants whose design involves little or no scale-up risk.

2.3 ENVIRONMENTAL HEALTH RISKS

Direct liquefaction processes, and to a lesser extent indirect processes based on Lurgi gasification, create significantly greater environmental health risks than other coal liquefaction processes. This stems from the complex organic compounds which are contained in the intermediate streams and high boiling point end-products of some of the liquefaction processes. In contrast, with indirect processes using entrained or fluidized bed gasifiers (such as Texaco, Koppers-Totzek, or Winkler) all the complex organic molecules are destroyed and converted to gas consisting primarily of hydrogen, carbon monoxide, carbon dioxides, water, and methane. Purified hydrogen/carbon monoxide mixtures are then catalytically converted to methanol, gasoline, or Fischer-Tropsch liquids, which have health risks similar to currently used liquid fuels: toxicity upon ingestion or inhalation, and some risk of cancer upon repeated contact, ingestion, or inhalation.[1]

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[1] Some indication of the frequency of accidents in refineries can be obtained from reported fire losses. According to data reported by the American Petroleum Institute covering the 1975-79 time period, there were between 1.15 to 1.42 fires (with losses exceeding $1,000) per refinery per year (API, 1977-80).

On the other hand, indirect processes using Lurgi gasifiers produce a wider range of organic compounds including some heavy oil and tars that contain polynuclear aromatic hydrocarbons and amines that have been associated with carcinogenic and mutagenic activity. The compounds are present in product streams from the gasifier and enter into wastewater streams during gas purification. Direct processes produce much greater amounts of these polynuclear aromatic hydrocarbons and amines. These compounds are contained almost entirely in the heavy products end (above 650°F), including intermediate streams, waste streams, and end-products. Occupational and public health risks from exposure are created because these compounds can enter the environment in several ways:

- Fugitive hydrocarbon emissions (i.e., leaks from valves, flanges, etc.);
- Releases during plant accidents;
- Releases in wastewater;
- Direct contact with direct process end-products; and
- Combustion products from using direct process liquids.

Even if developers of synfuels are aware of these problems, and taking particular care to protect workers, the degree of risks are highly uncertain at the present time. The principal issues are:

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[1] Cancer risk from compounds in gasoline and Fischer-Tropsch liquids as compared to direct process liquids are substantially lower (see Background Report and further discussion in this section). However, the range of the common compounds in gasoline, such as benzene, are implicated in elevated cancer rates (see Kingsbury et al. 1979).

- What fractions pose the greatest health risks?
- What are the types and degrees of risk?
- What are the possible mitigating measures? and
- What differences occur among technologies?

In order to answer these questions, systematic laboratory testing of process streams, plant emissions and effluents, and end-products is needed. The outcome of a program of initial biological screening tests could be available during the next several years. However, long term clinical or epidemiological data is always likely to be inadequate to substantiate human health risk (see Section 4).

One of the greatest environmental health concerns is the release of these highly toxic substances through "fugitive hydrocarbon emissons" (i.e., emissions from leaks in valves, flanges, pump seals, process drains, etc.).[1] This is a particular concern for direct processes because of the polynuclear aromatic hydrocarbons and amines in many of the process streams. Studies of existing oil refineries have shown high levels of nonmethane hydrocarbon (NMHC)[2] fugitive emissions implying that a potential for human exposure to these hydrocarbons exists. However, coal synfuel developers believe that such emissions can be substantially reduced through a "directed maintenance program." For example, for the SRC II demonstration plant it is estimated that 679 tpy of fugitive NMHC's will be emitted in an "unmitigated" case, but only 97 tpy with a "directed maintenance program." All developers contacted (represented by the six coal conversion technologies identified) are committed to such a program. However, what constitutes a directed maintenence program has not been rigorously specified, but generally it would require systematic monitoring for leaks and repairing those that exceed certain levels. To what extent such a program would reduce fugitive emissions and their associated risks is still unclear except that theoretically it would represent an improvement over conventional refinery practices.

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[1] The concentration and fate of toxic and carcinogenic materials in these fugitive emissions is uncertain. According to several studies, only liquids boiling above 650°F showed carcinogenic activity (see Background Report). Just what fraction of such a stream leaking from a valve would vaporize into the air or drip onto the ground is uncertain. The possibility is that both air and surface water pollution could result.

[2] Nonmethane hydrocarbons is a very broad spectrum since it includes every hydrocarbon from ethene and ethylene on up to asphalts (i.e., it is everything other than methane itself). Therefore levels of NMHC has no direct relationship to concentrations of carcinogenic hydrocarbons. For example, leaks from propane storage would yield high NMHC values in the complete absence of carcenogenic or mutagenic compounds.

2.4 PRODUCT AND CONVERSION EFFICIENCY DIFFERENCES

Differences in the products and in the conversion efficiency of various liquefaction processes can result in very different environmental impacts. For example, if two processes produce the same product but one has a higher conversion efficiency, then it will, on a per-unit-of-energy basis, cause fewer impacts associated with mining and liquefaction. Direct comparisons generally are not possible, however, because of uncertainties in the data (i.e., on energy conversion efficiency) and because of the wide range of products produced. Some processes produce all transportation fuel, such as the Mobil Methanol-to-Gasoline (MMG) process, whereas other processes produce more fuel oil suitable for stationary boilers. In addition, the MMG and methanol processes do not require any further refining step, whereas such refining is generally required with the direct processes to produce transportation fuels.

Figure 2-3 summarizes the product distribution from the six kinds of coal liquefaction processes. The proportion of each type of product can be varied somewhat; the proportions shown are those currently planned for demonstration and commercial plants (Rogers and Hill 1979). As shown in Figure 2-3, the indirect processes produce a much higher proportion of transportation fuels than the direct processes, which produce primarily heavy fuel oils. The direct processes can be adjusted to produce a higher fraction of transportation fuels; for example, the EDS process could be modified to shift the proportion of fuel oil from about 52 to 33 percent, with an attendant increase in naphtha and lighter fuels (Epperly, Plumlee and Wade 1980), but with a decrease in total throughput and thermal efficiency (see Figure 2-4).

In order to compare processes, Figure 2-5 gives three different bases[1] for comparing the "efficiency" of the six processes being

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[1] No single measure of energy efficiency is adequate; these three measures were chosen to illuminate the range of important considerations. However, even these three measures are inadequate in that they do not explicitly take into account (a) the differences in engine efficiency that different fuels might yield; for example, differences in miles per million Btu's between gasoline and methanol; and (b) energy requirements for additional refining (if any--see Section 2.5). In addition, efficiency calculations do not reflect the differences in fuel quality that two different processes might produce (e.g., middle distillates from Fischer-Tropsch are more suitable for producing diesel and jet fuels than similar fractions from direct processes).

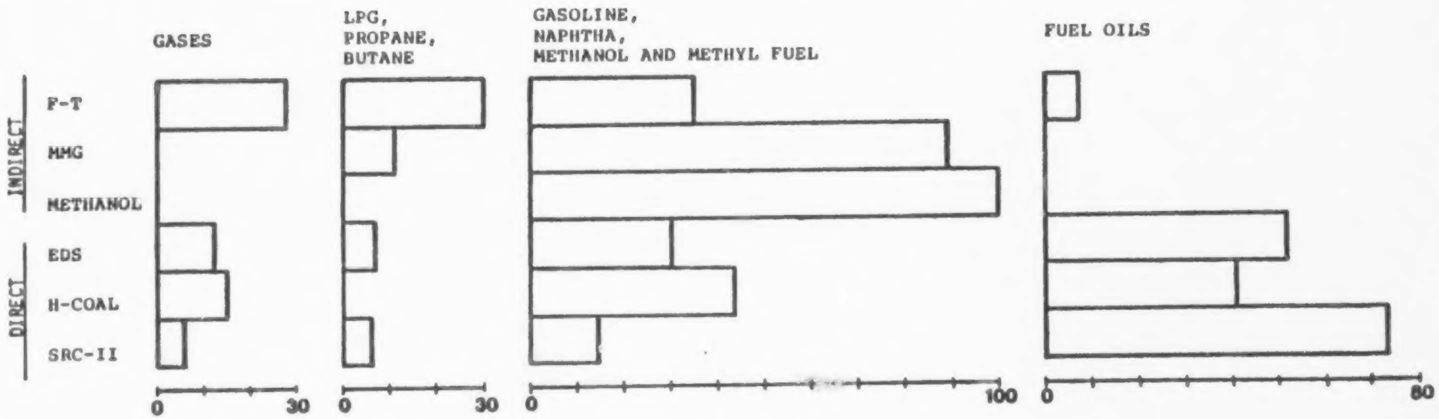


Figure 2-3: Comparison of product outputs. (product shares in percent on a Btu basis)

Source: Derived from Rogers and Hill 1979

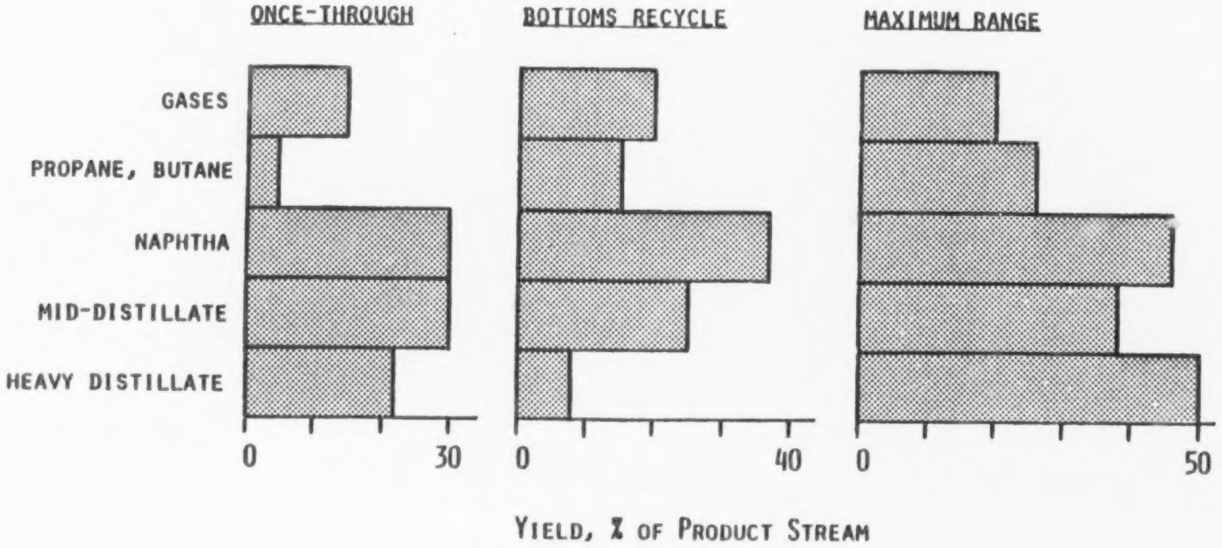
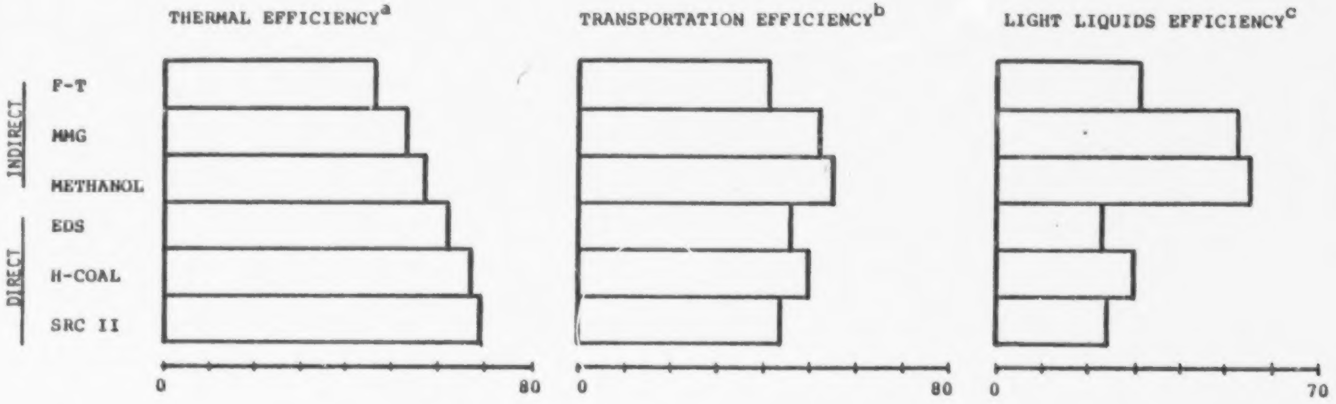


Figure 2-4: Range of Product Outputs from the Exxon Donor Solvent Process

Source: Adapted from Epperly, Plumlee and Wade 1980.



[a] Total hydrocarbon energy/total plant input with steam and electricity produced onsite.

[b] As in a, with total HC input corrected to indicate costs for upgrading to transportation fuel (gasoline grade) from the heavier fuel fractions.

[c] As in a, but include only hydrocarbons for transportation: propane, butane, LPG, methanol, naphtha, and No.2 oil.

Figure 2-5: Comparison of Conversion Efficiencies

considered. The first bar graph shows overall percent thermal energy efficiency (i.e., total Btu's output divided by Btu's of energy input). This comparison shows that the direct processes are substantially more efficient, ranging from the 69 percent SRC II process to the 46 percent Fischer-Tropsch indirect process. Accordingly, it would require 50 percent more coal, with all its attendant environmental and human health and safety impacts, to use Fischer-Tropsch process instead of the SRC II process for an equivalent Btu value of output.

At the other extreme, the "light liquids efficiency" is an index that only measures the thermal efficiency for producing fuels that can be directly used for transportation purposes with little or no upgrading. This includes the propane, butane, LPG, naphtha, and No. 2 fuel oil fractions. In this case methanol and methanol-to-gasoline have the highest efficiency, and the EDS and SRC II processes compare unfavorably. On this basis these latter processes would require two to four times the plant capacity to produce an equivalent amount of fuel that could be easily used by the transportation sector.

A third means for directly comparing these various processes is "transportation efficiency" represented by the middle bar graph of Figure 2-5. This "transportation efficiency" index is based on the Btu output of liquids, weighted against a value scale based on the economic cost of transforming that liquid to a high grade transportation fuel. For example, unleaded premium gasoline is weighted 1.0, the more efficient fuels of butane and propane are weighted

1.08 and 1.07 respectively (see Background Report, and Rogers and Hill 1979). Fuel oil is penalized, with a weighting of 0.56. Although the weights are based on economic costs and prices, they provide an approximation of transportation energy value of the product mixes at the liquefaction stage. When compared to thermal efficiency, the transportation efficiencies are lower across the board, reflecting the relative energy cost of upgrading coal liquids to transportation fuels. Methanol and methanol-to-gasoline processes have the highest "transportation efficiency," (54.6 percent and 52.2 percent, respectively), while Fischer-Tropsch and SRC II have the lowest (41.5 and 44.2 percent, respectively).[1]

2.5 UPGRADING AND REFINING

Comparison among the coal liquefaction processes should take into account the demand for the various products, and the feasibility and efficiency of refining and upgrading to meet market needs. From an environmental perspective, important factors include:

- How efficient will be the refining process to produce transportation fuels;
- Will grass roots refining capacity be needed; and
- What types of refinery impacts may occur.

The two classes of coal liquefaction processes have different refining needs. The MMG process produces a product directly usable as transportation fuel. The Methanol process can be considered to manufacture a blending stock for transportation fuels used in conventional engines, a feedstock for the MMG process, or pure ethanol to be used directly in appropriately modified engines. For these technologies, the conversion efficiencies described in the previous section represent the efficiencies for final products. For the Fischer-Tropsch process, a low octane gasoline (unsuitable for motor fuel unless upgraded) is a major product along with other transportation fuels such as diesel fuel. As indicated previously, some fuel oils are produced by the Fischer-Tropsch process which would require cracking and reforming to make transportation fuels.

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[1] This comparison does not consider the superior quality of diesel fuel from the Fischer-Tropsch process compared to similar fractions from direct processes. Thus, Fischer-Tropsch may not be distinguishable from other processes in about the 45 percent transportation efficiency range.

The direct coal liquefaction processes produce light, middle, and heavy distillate fractions, with proportions varying depending on the specific process type and the amount of "recycle" or the residence time liquids spend in reactor vessels. The light distillate or naphtha fractions of direct processes make good gasoline blending stock after reforming. The EDS and H-coal processes can produce up to two-thirds naphtha and one-third fuel oil to maximize liquids with transportation value. The SRC II process, as indicated earlier, produces a greater amount of heavy products, although its product slate is also variable. In all cases, however, significant refining of the range of liquids is required to produce high proportions of transportation fuels. Because of the extensive refining requirements, including large hydrogen requirements, refining to transportation fuels is an energy intensive process. Table 2-2 indicates the efficiency of refining SRC-II liquids to

TABLE 2-2: EFFICIENCY OF REFINING SRC-II LIQUIDS[a]

Refinery Characteristics	Total Input Btu Requirement[b] (10^6 Btu/day)	Product Output[c] (10^6 Btu day)		
		Gasoline	Jet Fuel	Efficiency
High severity hydrotreating	356,483	75,260	204,060	78.4
Intermediate severity hydrotreating	347,697	89,967	188,243	80.0
High severity hydrotreating and fluid catalytic cracking	352,423	265,000	--	75.2
Intermediate severity hydrotreating and single stage hydrocracking	335,524	265,000	--	79.0

[a] Refinery characteristics and data from Frumkin and Sullivan 1980.

[b] Includes a composite of SRC II syncrude, boiler fuel and electricity. SRC syncrude = 5.76 x 10^6 Btu/bbl; boiler fuel = 6.2 x 10^6 Btu/bbl; electricity = 10.5 x 10^6 Btu/MW. See Background Report.

[c] Gasoline = 5.3 x 10^6 Btu/bbl; jet fuel = 5.7 x 10^6 Btu/bbl.

gasoline and jet fuel. The low efficiency range, from about 75 to 80 percent, reflects the extensive cracking and hydrogenation requirements to upgrade these liquids.

The energy efficiency of refining improves as additional fuel oil remains in the product output (Frumkin and Sullivan 1980). Based on discussions with staff of direct process developers, they expect to utilize naphtha fractions as a gasoline blending stock and use heavier fractions to back out petroleum as a boiler fuel (Gulf Mineral Resources Co. 1980; Exxon Research and Development Corp. 1980; and Hydrocarbon Research Corp. 1980). In addition, environmental impact statement documentation for SRC II and SRC I facilities indicates that middle and heavy fractions will be used for boiler fuels (U.S., DOE 1981a, 1981b).

For these reasons, over the short term, environmental disturbances from additional refinery requirements for both direct and indirect coal liquids appear to be minimal. However, over the longer term if demand for transportation fuels cannot be met by petroleum liquids, refining direct process liquids to transportation fuels may be more favorable (Chevron Research 1981). Under these circumstances the most efficient refining operations for direct liquids would be from new grass roots refineries (Frumkin and Sullivan 1980) and refining coal liquids may be a significant environmental issue. Many of the issues are closely related to those for the liquefaction process itself, such as concerns about air and water quality, siting, and health considerations. The liquefaction processes can be ranked generally on the basis of additional refining requirements to meet transportation demand as follows (from major requirement to no requirement): (1) SRC II; (2) H-coal and EDS; (3) Fischer-Tropsch; and (4) Methanol and MMG.

3.0 WHAT ARE THE IMPORTANT LOCATIONAL FACTORS AFFECTING ENVIRONMENTAL IMPACTS?

The different regions of the country vary greatly in the type of coal resources and in the physiographic and social setting of these resources. These differences can affect both the type and size of commercial synfuels development and affect a range of air, water, land use, and ecological impacts. Within regions, small variations in location can influence both actual and perceived environmental impacts thus, local conditions are important to siting choices for individual plants. In addition, a range of institutional and economic factors affect siting choices and can result in site selections that conflict with environmental values. This section addresses three locational topics:

- Coal characteristics affecting regional location;
- Regional differences in environmental impacts; and
- Local differences in impacts within a region.

3.1 COAL CHARACTERISTICS

Several critical characteristics of coal affect where coal liquefaction plants may be deployed, including the size of coal deposits, the composition of coals, and the combustion characteristics. In addition, of course, a range of other environmental resources is required, including adequate land and water resources and a suitable workforce. Where coal liquefaction plants may be deployed and what coal resources may be developed are major concerns because they determine what regions and environments will be impacted by coal liquefaction. This section addresses how coal resources affect the choice and location of coal liquefaction technologies, while the following sections address environmental effects dependent on locational factors.

Liquefaction plants are most likely to be located in proximity to coal deposits (indicated in Figure 3-1). This is because transportation costs for shipping the coal would be substantially greater than the cost of transporting the volumes of liquid products that would be produced from that coal. However, shipping coal long distances (e.g., greater than 300 miles) is possible and would be dependent on the choice of transportation modes available and many siting factors. For example, construction costs for coal liquefaction plants in the Gulf Coast Province are substantially less than in the Northern Great Plains or Interior Provinces (Fluor 1979), reducing capital outlays in Gulf Coast locations. Because of the complexity of factors involved in siting facilities, it is not possible to determine the most favorable coal liquefaction facility location based on a single criterion, such as proximity to coal deposits.

Coal liquefaction processes vary in their suitability to certain coal types. Eastern and Interior bituminous coals are generally more suitable for direct liquefaction processes than western subbituminous coals and lignite. This difference in suitability is

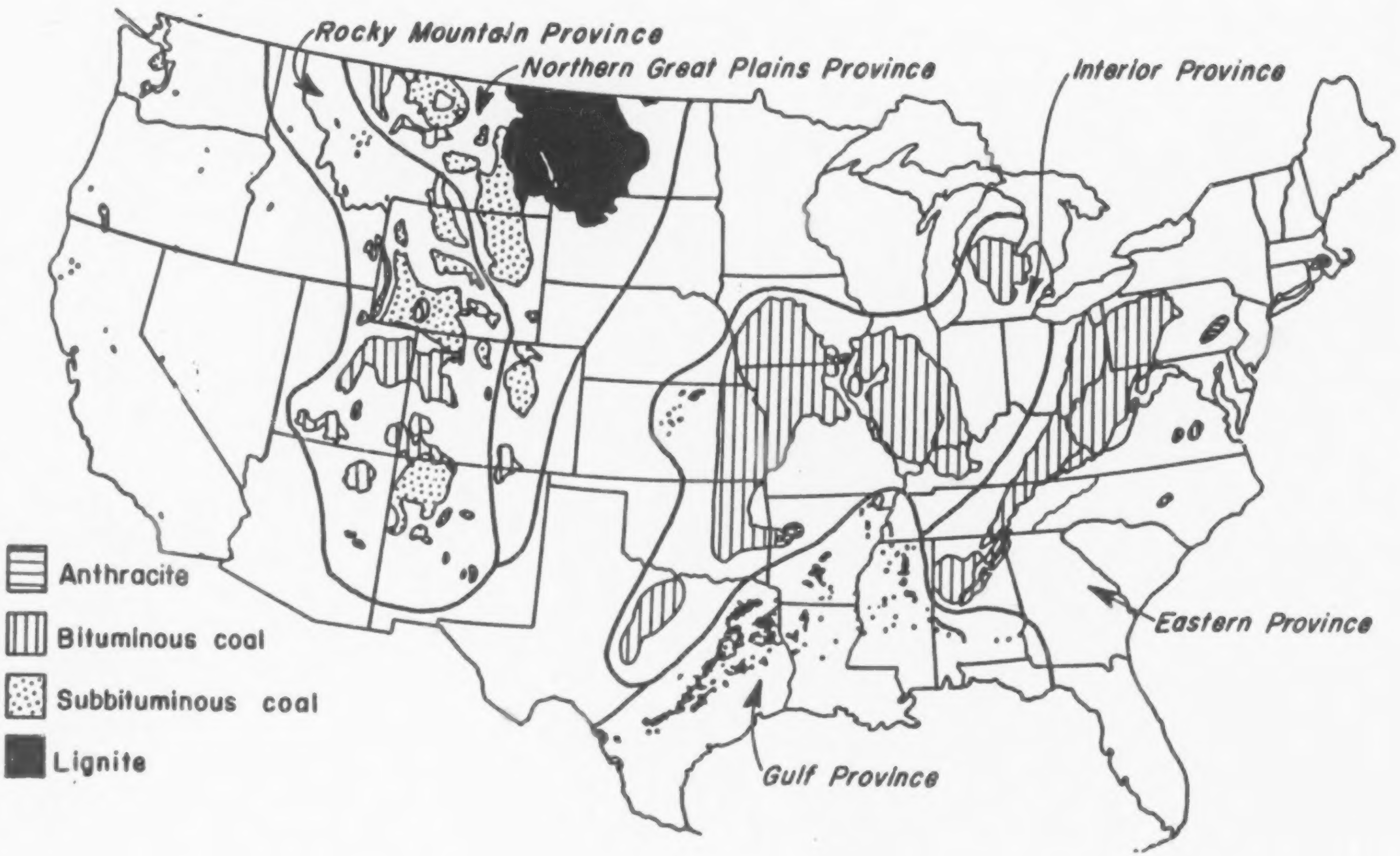
Rocky Mountain Province
Northern Great Plains Province
Interior Province
Eastern Province
Gulf Province
▤ Anthracite
▥ Bituminous coal
▨ Subbituminous coal
■ Lignite

Figure 3-1: Distribution of coal resources in the coterminous 48 states.

Source: Univ. of Okla., S&PP 1975.

generally due to the higher liquids yield from bituminous coals (Epperly, Plumlee and Wade 1980; Fluor 1979). The yield differences for direct liquefaction processes are due to the additional hydrogenation requirements needed for coals with high oxygen content, characteristic of western coals and lignite (Simbeck, Dickenson and Moll 1980). This hydrogenation requirement is represented by the hydrogen distance in Figure 3-2. The higher capital and operational cost for hydrogenation generally offsets the lower cost advantage of lower rank western coals and lignites (Simbeck, Dickenson and Moll 1980; Fluor, 1979). The SRC II process is not suitable for western coals because of their low pyritic iron content. This iron acts as an essential catalyst for the liquefaction reactions in the SRC II process. Currently, direct process plants have been proposed only for eastern locations.

The indirect processes can utilize a wide range of coals. Although, like direct processes, they have higher yields per ton of coal for higher rank coals, they do not directly hydrogenate coal and, thus, do not operate at such an economic disadvantage as the lower cost subbituminous coals and lignites. *For these reasons indirect process plants have been proposed for western as well as Interior and Eastern province locations*. In addition, some studies indicate that indirect processes may be more favorable in western locations due to the lower coal costs (Simbeck, Dickenson and Moll 1980).

The caking or agglomerating properties of coal at high temperature restrict some gasifier and reactor applications. However,

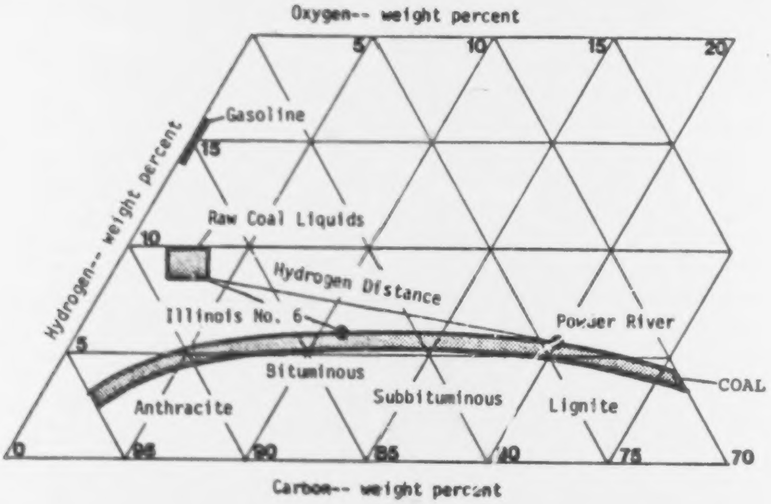

Figure 3-2: Direct coal liquefaction favors bituminous coals due to hydrogen requirements for oxygen.

Source: Adapted from Simbeck, Dickenson and Moll 1980.

recently even Lurgi gasifiers which were susceptible to clogging have been designed to accept caking coals.

In summary, direct processes are more likely to be deployed in Interior and Eastern coal regions than in Rocky Mountain, Northern Great Plains, or Gulf Coast coal provinces. Indirect processes have greater flexibility for utilizing different coals, potentially can be sited in a wide range of U.S. locations, and are perhaps favored in the West if coal costs remain lower there.

3.2 REGIONAL DIFFERENCES IN ENVIRONMENTAL IMPACTS

Table 3-1 presents key environmental factors affecting coal liquefaction impacts and describes how these impacts are affected by regional differences in these underlying factors. The thickness of coal seams, for example, results in more land disturbance in the

TABLE 3-1: REGIONAL CONDITIONS AFFECTING ENVIRONMENTAL IMPACTS

An EXISTING CONDITION	Determines an INTERMEDIATE EFFECT	Which partially determines an ENVIRONMENTAL IMPACT	REGIONAL IMPLICATIONS
Thickness of the coal seam	The amount of land disturbed	Ecological Impacts	Minable coal seam thickness ranges from less than several feet in the Eastern Province to more than 50 feet in the Northern Great Plains. Ecological impacts that are caused by direct land disturbance due to surface mining include preemption of wildlife habitat, recreational areas, and agricultural lands. These will be more serious in the East than in the West.
Sulfur content of the coal	Sulfur emissions	Air quality and ecological impacts	Average sulfur content ranges from less than one percent in the Northern Great Plains and Rocky Mountain provinces to more than four percent in the Interior Province. However, the potential for increased SOx emissions in the East is partially offset by the ability to add emission controls to a synthetic fuel facility. Sulfur emissions affect ambient air concentrations of SOx and acid rain formation; acid rain, in turn, reduces species diversity and productivity in terrestrial and aquatic ecosystems. These problems are, therefore, potentially more serious in the East than in the West.
Ash content of the coal	Solid waste amounts	Ecological and water quality impacts	Ash content ranges from about seven percent in the Northern Great Plains Province to as much as fifteen percent in the Eastern Province. Thus, the amount of solid waste that requires disposal is greater in the Eastern Province than in the Northern Great Plains. The amount of land required for solid waste disposal increases with ash content as do the ecological impacts caused by that disturbance. To the extent that leaching from the solid waste disposal sites occurs, water quality is affected.
Rainfall	Reclamation potential, potential for flooding, potential for seepage. The need to discharge effluents	Ecological and water quality impacts	Rainfall ranges from over 50 inches per year in parts of the Eastern Province to less than seven inches per year in parts of the Rocky Mountain Province. High rainfall is beneficial in the sense that reclamation is made easier and soils are generally better. It can, however, also cause problems: floods increase the likelihood of a spill from a waste disposal site; seepage and leaching from waste disposal sites increase with precipitation; and evaporation rates are lower causing water effluents to accumulate if not discharged. Thus, the high rainfall in the East reduces land impacts but increases water quality impacts; the reverse is true in the West.
Wind and inversion frequency	Air dispersion potential	Air quality impacts	A combination of wind and temperature conditions generally determines the potential for dispersion of air pollutants. While it varies both seasonally and by location within a coal province, it is generally very good in the Northern Great Plains and Gulf Coast provinces; this ameliorates air quality problems there.
Terrain	The potential for plume impaction	Air quality impacts	Rough terrain occurs through the Eastern Province and in parts of the Rocky Mountain Province. Consequently, the probability of plume impaction from synfuel stacks on elevated terrain is greatly increased; such impaction greatly increases ground level concentrations of air pollutants.

(continued)

TABLE 3-1: (Continued)

An EXISTING CONDITION	Determines an INTERMEDIATE EFFECT	Which partially determines an ENVIRONMENTAL IMPACT	REGIONAL IMPLICATIONS
Population density	Wilderness character	Ecological and human health impacts	The low population density of the Great Plains and Rocky Mountain coal provinces affects the ecological sensitivity of the area. Synthetic fuel development will cause an increase in population density in the West. This increase will fragment ecosystems, fragment wildlife habitat, alter the natural appearance of the West's vistas; and in general, change its open-space character. On the other hand, with lower population density, there are fewer risks of adverse human health effects from coal liquefaction pollution.
Existing agricultural lands	Changed land use	Agricultural impacts	Agriculture is sometimes in competition with energy development for land; the Interior Coal Province is characterized by prime agricultural land--some of the best in the U.S. While land reclamation following mining in that province is possible, reclamation to existing high fertility levels is questionable. Preemption of agricultural lands by coal mining is also an issue in the Northern Great Plains--not because the land is so fertile but because reclamation is in doubt and agriculture is a way of life there.
Existing ecosystems	Reductions or modifications to land and plants	Ecological impacts	Values associated with terrestrial ecosystems include uniqueness, vastness, wildlife habitats (including endangered species habitats), recreation, and productivity. The ecosystems in the West are valued very highly for their wilderness character, vastness, and high quality wildlife habitat; in the East they are valued more for their productivity.
Existing air quality		Air quality impacts	In general, air quality is worse in the Interior and Eastern provinces than in the Northern Great Plains or Rocky Mountain provinces; non-attainment with respect to one or more criteria pollutants is more of a problem in the East. The presence of poor air quality and non-attainment will make synthetic fuel development difficult. In the Rocky Mountain Province, however, the presence of many Class I PSD areas will make synthetic fuel development difficult.
Existing water quality		Water quality impacts	Streams in the Interior and Eastern provinces are, in general, more polluted with organic and inorganic chemicals than those in the Northern Great Plains and Rocky Mountain provinces; this could make synthetic fuel develoment in the East more difficult in water quality limited streams, where additional discharges may be restricted.

East than in the West. The sulfur and ash content of coal also affects the extent of air and solid waste impacts. Meteorological conditions can intensify some air impacts especially in the East where ventilation rates are low and the frequency of inversions is higher. Population density and the composition and character of existing ecosystems are also important. Table 3-2 summarizes how regional sensitivity to impacts from synfuels can vary.

Five ecological issues associated with synthetic fuel development provide a broad framework for examining the regional variations in environmental impacts:

- Degradation of air quality;
- Degradation of water resources, including native stream and riparian ecosystems;
- Degradation of terrestrial ecosystems from mining;
- Degradation of terrestrial and aquatic ecosystems due to acid rain, especially in the East; and
- Degradation of the overall ecological character of some areas.

These problems are not unique to synthetic fuel development, but are generally associated with any intense industrial development. Ecological impacts such as reduction in wildlife populations and changes in plant communities result from the cumulative effects of many disturbances. Coal liquefaction is just one of many industrial and social developments that disturb ecosystems; and, together with increasing industrialization in resource rich areas of the nation, it will contribute to progressive changes in ecosystems.

TABLE 3-2: FACTORS CONTRIBUTING TO REGIONAL ENVIRONMENTAL SENSITIVITY TO SYNTHETIC FUEL DEVELOPMENT
(relativey sensitivity)

Province	Air Quality	Water Quality	Water Availability	Ecological	Population Impacts
Eastern	Complex terrain and poor ambient air quality; scenic vistas (high)	Widespread existing pollution sources (high)	High rainfall and streamflow (low)	Valued forest lands (moderate)	Varied population density (moderate)
Interior	Poor ambient air quality (moderate)	Widespread existing pollution sources (high)	High rainfall and streamflow (low)	Varied land use (low)	Varied population density (low)
Gulf Coast	Locally poor air quality in some areas contributes to sensitivity; good ventilation (moderate)	Local existing pollution sources (moderate)	High rainfall and streamflow (low)	Varied land use (low)	Varied population density (low)
Rocky Mountain	Complex terrain and several Class I PSD areas; scenic vistas (high)	Limited flow; variable quality (high)	Limited rainfall and stream flow (high)	Valued recreation land (high)	Low population density (high)
Northern Great Plains	Good ventilation, good existing quality (low)	Moderate flow, variable quality (low)	Limited rainfall (moderate)	Agriculture cropland (moderate)	Low population density (moderate)

Air Resources

From an air quality perspective, synthetic fuel development will have the greatest impact in the Eastern and Rocky Mountain Coal Provinces. Rugged terrain and existing air quality regulations may make it difficult to site in some air quality control regions in the Eastern Province (Table 3-3). For example, several of the major coal producing areas of Kentucky and Tennessee are currently classified as nonattainment areas. In the West, existing air quality is excellent in the Northern Great Plains and good in most of the Rocky Mountain Region. However, complex topography and the numerous Class I PSD areas could constrain some developments in the Rocky Mountain Province (Univ. of Okla., S&PP 1981).

Water Resources and Aquatic Ecosystems

Synthetic fuel development will impact stream and riparian ecosystems in several ways:

- Consumption of between 3,500 to 5,900 AFY of water (for a 50,000 bbl/day plant), depending on the location and design;[1]
- Continuous and intermittent discharges of wastewater, which can degrade water quality and amplify stream flow variations;
- Water pollution from synfuel plants due to accidents and floods, and spills from product transport;
- Dissolved solids and sediment loading due to runoff from surface mines; and
- Acid mine drainage from surface and underground mines, especially in the East.

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[1] Although coal liquefaction facilities consume significant quantities of water, on a per-Btu basis they consume 3 to 4 times less water than power plants (see Ballard et al. 1980).

TABLE 3-3: AIR QUALITY CHARACTERISTICS AND PROBLEMS

Province	Existing Quality (No. of PSD Class I areas)[a]	Meteorological Pollution Potential (days)[b]	Terrain	Implications
Eastern	Numerous nonattainment areas; Some Class I PSD areas (7)	High (30-40)	Rugged (plume impaction)	Sensitive to siting in industrial and rural areas
Interior	Numerous nonattainment areas; Some Class I PSD areas (5)	High (20-40)	Flat to rolling hills	Sensitive to siting in industrial areas
Rocky Mountain	Nonattainment areas in central cities; Numerous Class I PSD areas (46)	Moderate (0-20 potential pollution days)	Very rugged (plume impaction) potential stagnation	Very sensitive to siting; potential limitations to big levels of development
Northern Great Plains	Some attainment areas; Some Class I PSD areas (9)	Low (0-10)	Flat	Fewer air quality limits to development
Gulf Coast	Nonattainment areas in central cities; Few Class I PSD areas (1)	Low (0-10)	Flat	Limitations to development in some industrial areas

[a] PSD Class I areas within 300 miles of coal deposits; compiled from Garvey *et al*. 1978.

[b] Total number of forecast days of high meteorological potential for air pollution (U.S., DOE 1979).

Degradation of floodplain productivity and wildlife habitat as well as aquatic habitat could accrue from these changes. The extent of that degradation, however, will be critically dependent on site-specific conditions. Also, these impacts and issues are highly uncertain and controversial because such changes are difficult to quantify and are usually the cumulative result of many human activities.

As indicated in Tables 3-2 and 3-4, from a water availability perspective, the Eastern Region is more suitable than other regions for synthetic fuel development. Water is more abundant there although conflicts over appropriate use are emerging (Ballard et al. 1980). In the West the lack of precipitation causes water availability problems--most severe in the Colorado River Basin and in parts of the Northern Great Plains Region. From a water quality perspective, however, eastern locations are already receiving a great range of industrial and municipal discharges. In these locations, water quality may be least suitable for receiving discharges from coal liquefaction plants.

Terrestrial Ecosystems

The large coal requirements for a synfuels industry can lead to substantial land impacts, especially those associated with mining. A midrange estimate for the area of mined lands disturbed for coal liquefaction can be obtained by disaggregating coal supply to eight national coal supply regions and utilizing estimates of land area disturbed by surface mining based on average regional coal deposit characteristics (see Table 3-5). This results in a production

TABLE 3-4: WATER RESOURCES AND AQUATIC ECOSYSTEMS: CHARACTERISTICS AND PROBLEMS

Province	Ecosystem Types	Existing Primary Stresses	Coal Liquefaction Effects	Implications (primary problems)
Eastern	Mid and low altitude lakes; primarily continuous flowing streams and rivers	Eutrophication; acidification; siltation; organic and inorganic pollution	Discharges to receiving stream; water consumption; potential groundwater pollution; spills	Sensitive to incremental organic and inorganic pollution; additional impoundments (water quality)
Interior	Low altitude lakes; primarily continuous flow streams	Eutrophication, acidification, siltation	Discharges to receiving streams; water consumption; potential groundwater pollution; spills	Sensitive to incremental organic and inorganic pollution (water quality)
Rocky Mountain	High altitude lakes; continuous and intermittent stream types	Siltation; some pollution; impoundments	Water consumption; potential ground water pollution; spills	Sensitive to stream flow reduction (water availability and habitat modification)
Northern Great Plains	Continuous and intermittent streams	Siltation; eutrophication	Water consumption; potential groundwater pollution; spills	Sensitive to additional biological oxygen demand; local stream flow reduction (water availability)
Gulf Coast	Coastal lagoons, marshes; estuaries; broad rivers and flood plains	Drainage; filling; eutrophication	Water consumption; potential groundwater pollution; spills	Sensitive to population growth and habitat modification; pollution (water quality habitat modification)

TABLE 3-5: ANNUAL PATTERN OF LAND USE FOR COAL SURFACE MINING PROJECTED IN 1985

Supply Region	Regional Proportion of Total U.S. Surface Mining Production[a]	Proportion of Coal Surface Mined Within Each Region (%)	Surface Area Disturbed (acres per million tons production)
Northern Appalachia	12	47	127
Central Appalachia	13	31	214
Southern Appalachia	2	57	125
Eastern Interior	16	48	160
Central and Gulf Coast	9	98	107
Northern Great Plains	40	100	21
Rocky Mountains	1	38	102
Southwest	7	98	52
	100		
U.S. Average (production weighted)		62	98

Source: Based on data in U.S., DOE 1979.

[a] Projected total U.S. coal production of 1,080 tpd by 1985; 671 tons are surface mined (U.S., DOE 1979).

weighted U.S. average of 98 acres disturbed per million tons of coal produced by surface mining. Thus, a two million bbl/day synfuel industry utilizing 300 million tons of coal a year (with 62 percent surface mined) would disturb about 850 square miles from surface mining over a 30 year period.[1] Note this figure does not include surface disturbances from underground mining, such as coal cleaning areas, storage or subsidence effects.

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[1] The projected patterns are based on a major use for coal as an industrial and boiler fuel; thus, it may be biased against Interior and Appalachian coal, which is most suitable for direct processes (see Section 3.1). A shift to using greater proportions of Appalachian and Interior coals would favor underground mining and might reduce the extent of surface disturbance. This reduction would be counterbalanced to some extent by larger areas disturbed per ton of coal supplied from surface mines in the Interior and Appalachian regions (Table 3-5).

In addition to mining, terrestrial ecosystems are modified by transportation, processing facilities, solid waste disposal, and by urban growth associated with increased industrialization. Impacts from coal liquefaction activities are related to the degree that modifications to terrestrial environments can be assimilated or "absorbed" by the ecosystem. In areas with rich soils and moderate-to-high rainfall such as the Gulf Coast, Interior, and Eastern provinces, regrowth of vegetation occurs comparatively rapidly following a disturbance such as surface mining. However, some characteristics of the Eastern Province such as complex topography, make restoration of environmental features difficult and contribute to reclamation problems. Table 3-6 identifies some general characteristics of terrestrial ecosystems in the major coal producing regions where coal liquefaction may occur.

Based on the existing patterns of communities and stresses, the Gulf Coast terrestrial ecosystems appear able to absorb mining impacts substantially, and regrowth of dominant plant species is quite rapid. In the Eastern sections of the Gulf Coast Lignite Province, for example, forest areas act as an additional buffer, providing capacity for significant local and regional development.

In contrast, the arid and semiarid regions of the Rocky Mountains have a slower regrowth, and animal species are less buffered by dense forest stands in many areas. Thus, Rocky Mountain

TABLE 3-6: TERRESTRIAL ECOSYSTEMS: CHARACTERISTICS AND PROBLEMS

Province	Ecosystem Types	Existing Primary Stresses	Coal Liquefaction Effects	Implications (problem importance)
Eastern	Pine forest; maple, oak, hickory forests; agricultural lands	Urban growth, mining	Increased mining; industrial growth; localized deforestation	Numerous stresses; ecosystems somewhat resilient (ecosystems can absorb some coal liquefaction development)
Interior	Oak-hickory forest; grasslands; agricultural lands; pine forests	Urban growth; mining; agriculture	Increased mining; industrial growth; localized grassland and crop removal	
Rocky Mountain	Subalpine forest; ponderosa pine forest; sagebrush grassland	Urban growth; mining; recreational activities; and local land conversion	Increased mining; industrial growth locally near required transportation corridors; local deforestation	Numerous stresses; some ecosystems relatively fragile (ecosystem can absorb relatively little development
Northern Great Plains	Grassland; cropland; riparian deciduous trees; pine forests	Agricultural development	Increased mining; industrial growth	Comparatively few stresses, ecosystems resilient (ecosystem can absorb substantial development)
Gulf Coast	Grassland; cropland; pine forests	Urban growth; agriculture; industrial development	Increased mining; industrial growth	Numerous stresses but ecosystems resilient (ecosystems can absorb substantial development)

terrestrial ecosystems are more sensitive to direct disturbances than Gulf Coast or Eastern ecosystems.

Linkage Between Air, Water, and Land Resources: Acid Rain

Synthetic fuel facilities produce NO_x and SO_x, and these pollutants in combination with moisture in the air form nitric acid and sulfuric acid--acid rain. Particles containing sulfate, nitrate, and chlorides can also settle from the air without atmospheric moisture. These particles can then acidify soils, streams, and lakes. Although acid rain has been a problem associated primarily with the Northeast, it is now spreading to the Southeast and perhaps even to the West. In all these regions, 10 to 50 percent of the acid deposition may be dry (Kerr 1981). The possible damage in reduced productivity and loss of species over the long term is highly uncertain with present knowledge, but may be very significant (U.S., EPA, ORD 1980). Multiple coal liquefaction plants could contribute to a significant proportion of the NO_x and SO_x emissions as measured against 1975 levels of emission (Table 3-7).

Even in regions where existing air pollution levels are low, such as the Rocky Mountains and Northern Great Plains, localized acidification has been measured. Although both the levels of development and potential impact in western regions are uncertain, possible elevated levels of sulfur and nitrogen oxides (as illustrated in Table 3-7) raise concerns in the Rocky Mountain and Northern Great Plains Region because of plant species known to be sensitive to acidification, including pines and wheat (U.S., EPA, ORD 1980; White *et al*. 1979). Thus, acid rain and dry deposition

TABLE 3-7: EXAMPLES OF POTENTIAL CONTRIBUTORS TO ACID RAIN (thousands of tpy)

	A Local Case 260,000 bbl/day in Henderson Co. Kentucky[a]		A Regional Case One million bbl/day Liquefaction in Montana, North Dakota, and Wyoming	
Conditions	SO_2	NO_x	SO_2	NO_x
1975-1976 Emission Level	266	57	1,123	339
Synfuel Plants[b]	50	74	110	110
Percent Increase	23%	130%	10%	32%

[a] See Enoch 1980.

[b] Note range of emissions among regions reflects different coal compostion and technology combinations.

stemming, in part, from synthetic fuels development are likely to remain an ecological issue and to increase in importance as an agricultural issue.

Overall Ecological Characteristics

Finally, there are unique and special values associated with the wilderness character of some areas--particularly the Rocky Mountain region--which could be changed by large scale synfuels development. A desire to preserve the "Big Sky Country" and the "wide open spaces" is expressed by citizens across the U.S. Coal mines, liquefaction plants, and other energy facilities, along with the added population increases would:

- Change local land use patterns;
- Degrade air quality, including visibility;

- Increase water consumption;
- Lower water quality; and
- Increase pressures for recreational space (White et al. 1979).

In combination, these modifications would alter the unique and special features of some western locations.

Incrementally, changes brought about by development are small; for example, the amount of land used by direct development of mines and liquefaction facilities would in most cases be between 0.05 and 1.0 percent of the land area of any one county with coal resources under projected ranges of potential development (White et al. 1979). Thus, in many cases, changes are more likely to be perceived impacts than measured ones. Exceptions to this may occur where facilities would be concentrated around the major coal development communities such as Gillette, Wyoming, and Farmington, New Mexico.

The broader ecological issue is not that ambient air concentrations will exceed standards, that water will become polluted, or that coal mines will preempt ranchland; rather, the issue is multifaceted and based on values and perceptions stemming from the combination of changes brought about by industrial and urban development in any area.

Many western areas are viewed as the only pristine areas left, and coal development will locally change that. The potential for that change in social and ecological character is a major source of conflict.

3.3 LOCAL FACTORS AFFECTING ENVIRONMENTAL IMPACTS

Within regions, several site-specific factors can influence the kind and extent of environmental impacts. Table 3-8 identifies several factors affecting air, water, solid waste, ecological, and public perception impacts. For example, locating a plant in an elevated area can reduce local air quality problems because the pollutants will be dispersed over a wider area and diminish plume impaction on terrain. Avoiding areas of critical habitat and flood plains can help to reduce ecological problems and the chances for water pollution. Thus, locational differences of just a few miles may be very important in preserving environmental values.

TABLE 3-8: LOCAL FACTORS AFFECTING ENVIRONMENTAL IMPACTS

Environmental Impact Category	Locational Factors
Air Quality	Dispersion potential Proximity to nonattainment area Proximity to PSD Class I area Elevated terrain
Water Quality	Proximity to flood plain Proximity to water-quality limited streams Aquifer characteristics
Solid Waste	Proximity to flood plain Presence of porous soils (sand, sandstone, loam)
Ecology	Presence of critical habitat for endangered species Presence of wildlife refuges Presence of breeding habitat Wetlands and riparian habitat
Perception	Proximity to towns and cities Proximity to archaeological sites Public perceptions of development

An increasingly important factor in industrial development is public reaction to a facility. For example, the visibility of a facility and the plume from its stacks are often regarded as negative aesthetic and environmental impacts. This apparently is the case for the Morgantown SRC-II demonstration plant, which would be easily seen from the University of West Virginia campus. Many residents of Morgantown consider the high visibility of the plant and fear of adverse impacts as changing the character of the area from a small university town to an industrial city (see also Section 4.3). An alternative location just a few miles away could have avoided this problem.

Table 3-9 indicates the proximity to population centers of five coal liquefaction demonstration or commercial facilities at an advanced planning stage. Three of the facilities are within 4 miles of towns with populations of 20,000 or more. The other two facilities, although located near small towns, are 10 to 25 miles from larger population centers.

Although these local factors can be very important to the environment, they are usually less important to developers than economic factors. Table 3-10 identifies the initial criteria used by developers to select sites for two demonstration plants. As indicated, important economic factors affecting plant location are:

- Proximity to the coal resource;
- Proximity to transportation systems (for example, navigable rivers);
- Availability of water supply and receiving water for discharges; and

TABLE 3-9: SURVEY OF SITES SELECTED FOR COAL LIQUEFACTION PROJECTS AT ADVANCED STAGE[a]

Plant Description	Status	Location	Distance to Nearest City of 20,000 or more (miles)	Families Displaced at Site	Distance to Nearest Town (population size)
SRC-I Demonstration 6000 tpd	Draft EIS filed	Newman, Davies Co., Kentucky	Owensboro (10)	24	0.0 to 0.6 miles to Newman (400)[b]
SRC-II Demonstration	Final EIS filed	Ft. Martin, West Virginia	Morgantown (4)	10[c]	4 miles to Morgantown (71,000)
W.R. Grace Mobil Methanol-to-Gasoline 28,900	Preliminary design	Baskett, Kentucky	Henderson (3)	NA	1 mile to Baskett (250)*
Tri-State Synthetic Fuels Project 30,668 tpd Lurgi-Fischer-Tropsch	Preliminary design	Henderson, Henderson Co., Kentucky	Henderson (3)	NA	3 miles to Henderson (23,000)
H-coal 23,000 tpd	Preliminary design	Breckinridge Co., Kentucky	Owensboro (25)	NA	6 miles to Cloverport (1,208)

NA = not available

*Kentucky Dept. of Commerce.

[a] Advanced stage indicates that permitting, or environmental impact statement process, or site acquisition has been initiated.

[b] When expanded to commercial size, plant border would be across the railroad tracks from downtown Newman.

[c] Estimated from number of residences within site boundaries.

TABLE 3-10: INITIAL SITE REQUIREMENTS SPECIFIED FOR COAL LIQUEFACTION DEMONSTRATION PLANTS

Requirement	SRC I Demonstration Plant	SRC II Demonstration Plant
Coal Supply	Not specified	"Large reserves close"
Transportation	Navigable river; rail contiguous or nearby	Rail, highway, and barge access
Land (acres)	800 to 1,000 "suitable shape" and topography	1,300
Water (gallons per minute)	16,000	15,000 to 80,000[a]
Services	Not specified	Labor market adequate
Other	Ash disposal site (at least half of the site above 100 yr. flood elevation)	40 megawatts electricity supply

Source: Compiled from U.S., DOE 1981a, 1981b.

[a] Range reflects choices of consumptive use for closed cooling (15,000) or once-through cooling (80,000).

- Proximity to adequate housing and public services for workforces and their families.

The importance of water and access to transportation corridors is indicated by the fact that all five proposed demonstration and commercial scale liquefaction plants (i.e., the five identified in Table 3-9) have been sited adjacent to navigable rivers. However, this also means that most coal liquefaction plants are sited partially or entirely on wetlands and floodplains. This can result in damage to wetlands habitat, water pollution from flooding, and failure to consider elevated terrain locations.

In an attempt to determine the most important considerations for siting a facility to convert coal to synthetic fuel, the Oak Ridge National Laboratory (Berry et al. 1978) used a panel of experts to generate a set of siting criteria (Table 3-11). The proximity of required raw resources (high-sulfur coal and water) and air quality were considered most important. The priority concern for air quality was to site conversion plants in areas not designated by the EPA as Air Quality Maintenance Areas--regions in which future air-quality degradation will be carefully monitored by regulatory agencies.

A number of siting analyses have been conducted which, together, have taken into consideration a wide variety of factors--resource availability, environmental impacts, production capabilities, availability of transportation, institutional and legal barriers, and prior commitment of the resources. Three studies (by the U.S. Geological Survey, the Bureau of Mines, and SRI International) used somewhat different criteria but identified 120 counties in common as potentially suitable for siting coal gasification and indirect liquefaction facilities (Hagler, Bailly 1980). In the Southern U.S., for example, eight Kentucky counties (Henderson, Hopkins, McLean, Muhlenberg, Ohio, Pike, Union, and Webster) and two New Mexico counties (McKinley and San Juan) were included. In addition, an ORNL analysis of the southeastern region of the U.S.

TABLE 3-11: SITING CRITERIA FOR A COAL CONVERSION FACILITY

Variable (order of relative importance)	Category or Value	Compatability[a] Index
Water availability	Adjacent to stream with 7-day/10-year low flow >194 Mgd	10
	Adjacent to stream which could have 7-day/10-year low flow >194 Mgd if additional regulation were imposed	4
	Adjacent to Great Lakes	8
	Adjacent to Atlantic Ocean or Gulf of Mexico	
AQMA	Not an AQMA	10
	Partially an AQMA	5
	Entirely an AQMA	-
Accessibility of high-sulfur coal (>1.9% S)	Values represent calculations from gravity model using tonnage of high-sulfur coal	
	Highest value	10
	Lowest value	1
	>100 miles from high-sulfur coal reserve	-
Barge accessibility	Adjacent to channel of >9 ft. depth	b
Seismic activity	Activity level I (lowest risk)	10
	Activity level II	5
	Activity level III (highest risk)	0
Rail accessibility	Adjacent to medium- or heavy-duty railroad	10
	Not adjacent to medium- or heavy-duty railroad	0
Accessibility of low-sulfur coal (<1.9% S)	Values represent calculations from gravity model using tonnage of low-sulfur coal	
	Highest value	10
	Lowest value	1
	>100 miles from low-sulfur coal reserve	6
Population density	90-100% of county has >500 inhabitants per square mile	0
	80-90%	2
	70-80%	3
	60-70%	4
	50-60%	5
	40-50%	6
	30-40%	7
	20-30%	8
	10-20%	9
	0-10%	10-9

Mgd = thousand gallons per day

AQMA = Air Quality Maintenance Area

- = excluded from consideration as potential candidate counties

Source: Berry *et al.* 1978, p. B-23.

[a] 10 = compatible; 0 = least compatible;

[b] Score equals number of miles of channel (maximum is 94.6)

included Sequoyah and Muskogee, Oklahoma; Bowie and Shelby, Texas; Marengo, Wilcox and Green, Alabama; and Stewart, Tennessee.

It is interesting to note that the results obtained by the various siting analyses frequently did not identify the areas where developments are actually being planned. In addition to sites identified in the siting studies, coal synfuel facilities are being planned in Florida, North Carolina, Arkansas, Louisiana, and in other areas within a given state other than those counties included in the siting analysis. In part this is because there are important institutional and social considerations that may affect where facilities are deployed. Among these are perceived economic gains from development and the willingness of some states to actively seek industrial development, while others may express hesitation. For example, Kentucky has actively participated in site acquisition to facilitate synfuel development, while some coal rich states, such as Colorado, have not been actively acquiring sites.

4.0 ARE OUR INSTITUTIONAL MECHANISMS ADEQUATE TO ENSURE ENVIRONMENTAL PROTECTION?

In addition to the technological and locational factors discussed previously, developing a large-scale coal liquefaction industry with adequate environmental safeguards requires institutional mechanisms for anticipating adverse impacts and implementing needed mitigation measures. Effectively managing synfuel development requires:

- Scientific information on physical, biological, and social effects of the coal liquefaction fuel cycle;

- Criteria for siting facilities in acceptable locations;
- A framework for choosing appropriate technologies and development schedules; and
- Criteria for acceptable or adequate operating procedures.

The following section addresses several issues indicating the difficulties in environmental management of synfuels development and areas where environmental management can be improved. These include:

- Environmental risks that are difficult to monitor and detect;
- Adequacy of environmental standards and compliance incentives;
- Effects of public perceptions; and
- Adequacy of environmental research programs.

4.1 MONITORING DIFFICULTIES

Environmental risks from synfuels will be difficult to measure and many could appear only after an extended time period, making it more difficult or impossible to reduce their impacts. This element of risk is associated with many technologies. For example, leaching from solid waste disposal areas can pollute groundwaters many years later--and once groundwater is polluted it is very difficult, if not impossible, to clean up.

In this regard, special concerns with coal liquefaction plants are the potential environmental hazards from low levels of hydrocarbon and trace element emissions. Low levels of these pollutants are difficult to monitor, and their effects are difficult to detect. For example, no standards exist for monitoring polynuclear aromatic hydrocarbons and polynuclear aromatic amines. These chemicals present the greatest carcinogenic health risk to the general public and plant workers.

Four categories of difficulties in detecting these environmental risks are summarized in Table 4-1. These are:

(1) The diversity of pollutant sources makes frequent measurements costly and time consuming;

(2) Even low concentrations and limited exposure can produce adverse health effects because some chemicals have high toxicity;

TABLE 4-1: DIFFICULTY IN DETECTING ENVIRONMENTAL HAZARDS

Hazards Information Need	Monitoring Problems	Detection Limits	Delays In Detecting Problems
Toxic organics pollution levels	Number of process sources (i.e., air, water, and solid wastes stream) and variety of chemicals	Difficulty in detecting low concentrations and cumulative releases	Monitoring may be infrequent (every 6 months to a year)
Trace element pollution levels	Number of process sources and variety of elements	Low levels of some trace elements make monitoring difficult	Monitoring may be infrequent (every 6 months to a year)
Pathways to human exposure	Multiple pathways; seasonal and geographic variation	Detection and relating to source difficult	Effects from bioaccumulation may occur over long time periods
Disease Incidence	Large population size and geographic movement of population	Some effects are difficult to determine and relate to source	Up to 10 or more years latency for some diseases (i.e., cancer)

(3) Surveys and clinical tests rarely prove cause and effect relationships; and

(4) Long latency periods make disease measurements and effects prediction nearly impossible over the "short" term (up to 10 or more years).

Thus, managers of the synthetic fuels industry are likely to be inadequately informed about the chronic health risks to workers and the general public. Dramatic cases of overexposure most readily document adverse health effects; however, even these incidents often only provide information ten to twenty years after the initial exposure. If a synfuels industry is to become commercial, it is important that as much information as possible concerning the degree of these health risks be generated at pilot or demonstration plant phases. (Section 5 elaborates on the problem of increased environmental risks with rapid development schedules.)

4.2 ENVIRONMENTAL STANDARDS AND COMPLIANCE INCENTIVES

Several options exist for achieving environmental objectives:

- Economic incentives that encourage compliance with environmental standards;
- Government programs for regulation, monitoring, and enforcement that provide assurances for achieving standards; and
- Operator standards of performance based primarily on industry consensus.

Economic incentives exist where adverse environmental impacts are tied directly to increased production costs. Unfortunately, as with many industries, the economic incentives for meeting environmental objectives in coal liquefaction plants are often not directly related to economic benefits. To illustrate, coal liquefaction plants operating under normal conditions may have 99.8 percent removal of particulates in air emission stacks. Should a process upset occur one percent of the time, resulting in by-passing particulate removal equipment, total plant emission would increase 5-fold or more. However, product costs might typically only increase one percent or so reflecting lost production time. When economic incentives are not sufficient, then more overt management actions may be needed. Three management deficiencies for controlling adverse environmental effects have been identified. These are:

- Poor quality control of some government sponsored programs;
- The need for new environmental standards for some problem areas; and
- The need for industry consensus standards.

Each of these is discussed briefly below.

Construction Quality Control

An example of poor quality control can be found in reviews of construction practices for a coal liquefaction pilot plant in Kentucky, where deviations from accepted standards were found (U.S., DOE, Off. of Inspector General 1979) including: poor control of equipment and materials procurement; inadequate planning to permit effective maintenance during operation; and deficient weld inspections and recordkeeping.[1]

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[1] In contrast, a review by the General Accounting Office of the construction of the 250 tpd EDS pilot plant at Baytown, Texas, gave a favorable report (U.S., GAO 1981). As further evidence of the construction quality, the unit was brought on-stream with relatively little difficulty.

A range of factors contributed to these deficiences (U.S., DOE, Off. of Inspector General 1979):

- The construction subcontractor did not have a quality control program;
- The construction contracts failed to specify quality assurances duties;
- Work supervisors had a lax and apathetic attitude toward construction safety; and
- Radiographic testing of high pressure piping was inadequate, in part because government oversight agency responsibility was deleted from DOE agreements.

Government participation in developing a coal liquefaction industry may shift responsibilities from developers and their subcontractors to the government supervisory program. *In this situtation economic incentives for environmental compliance by private industry can be short-circuited*.

Environmental Standards

Some critical environmental standard and enforcement programs are proposed but not now in place. Perhaps the most critical to the coal liquefaction industry are proposed standards to control carcinogenic hydrocarbons. Information contributing to these standards is not based on coal liquefaction or even refinery experience, but rather is based on studies at selected chemical plants (U.S., EPA, Research Triangle Park 1981). Draft generic standards describing monitoring and maintenance to control fugitive airborne carcinogens were issued in October 1979 (*Fed. Reg*. 1979), but final standards have been indefinitely delayed. If issued, *proposed standards may require monitoring and maintenance programs (Fed.*

Reg. 1979) but procedures and mechanisms to ensure compliance have not been determined.

The difficulties imposed for coal liquefaction by the absence of standards are four-fold:

- It is not possible to assess the potential carcinogenic risk, or evaluate the other health risks from coal liquefaction facilities;
- There is no basis to evaluate plant design or monitoring programs;
- There is no assurance that the public is protected from operators that may fail to meet established standards; and
- Assurances of enforcement or liability are not established through any formal means.

Industry Consensus Standards

Because of the broad range of safety and environmental concerns, it may be difficult to develop comprehensive government programs to regulate all environmental and safety concerns of a coal liquefaction industry. The development of adequate construction and operator performance may be stimulated by industry consensus standards. For example, the American Society for Metals establishes material standards; the American Society for Testing and Materials specifies testing approaches; the American Society for Mechanical Engineers develops standards for equipment; and, in coordination with technical societies and industry, the American National Standards Institute develops standards for components and operating systems.

Although general standards have been developed for petroleum refineries and hydrocarbon processing facilities, many of which are applicable to coal liquefaction, areas where new standards may be especially important for coal liquefaction plants include:

- Hydrocarbon monitoring;
- Design and maintenance standards for pipes and fittings operating with high pressure and high flow streams containing entrained solids;
- High pressure let-down valve designs where solids are entrained in liquid streams; and
- Vent/flare combustor systems handling entrained solids.

Much of the emphasis in plant design has focused on plant efficiency and performance. Important health and safety research such as fault free analysis and failure mode and effect analysis, for example, have not yet been applied despite the potential hazards in a coal liquefaction plant.[1]

4.3 PUBLIC PERCEPTIONS

The perceptions and attitudes of the public toward coal liquefaction have the potential for influencing such institutional concerns as site selection, environmental standards, and the pace of development. Based on recent indicators, at least three important concerns are evident:

- The general public appears to be relatively uninformed about synthetic fuels;
- No consensus exists about the potential severity of environmental and human health impacts; perceptions range from very optimistic to very pessimistic; and

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[1] Fault free analysis and failure mode and effect analysis are systems approaches to improving safety which have been applied in such critical areas as nuclear power plants, space programs, and offshore oil platforms.

- The lack of credible information available about the impacts from coal liquefaction makes the resolution of policy conflicts more difficult.

Public opinion toward synfuels development has received little attention to date. However, based on results from a 1980 national survey, the public appears relatively uninformed about synthetic fuels. Only 37 percent of those polled knew what synthetic fuels were; 15 percent defined them incorrectly, and 42 percent said that they didn't know anything about synthetic fuels (U.S., CEQ 1980). However, few respondents (9 percent) opposed support for synfuels, in contrast to the 33 percent who ranked nuclear power as the lowest priority.

Siting of industrial facilities, including energy conversion plants, has become increasingly difficult, in part because of public reactions to the potential risks. Thus, proposals to locate synthetic fuel plants close to towns can also expect public resistance. The extent of this resistence is uncertain and certainly subject to change--for example, as more is learned about health risks.[1]

In the case of the SRC II Demonstration Plant, some parties-at-interest to the development believe that the public is being used in an experiment to evaluate the environmental acceptability of the plant. This perspective is expressed in a letter from an industrial hygienist representing the Monongahela Alliance for Community Protection:

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[1] As an example of public concerns associated with the SRC II plant in West Virginia, twenty-five letters were received from state residents on a draft EIS; three letters were supportive, three were neutral, and nineteen were strongly opposed (compiled from U.S., DOE, 1981a).

> The most shocking part of the EIS is its clear implication that the demonstration plant is intended as a health experiment in which the workers and residents of the region are to be the guinea pigs (Becker 1981).

Public concerns are likely to intensify if visible upsets, such as fires, flaring, spills, or strong odors, occur in the synfuels demonstration program. Such upsets are expected to occur more frequently during this demonstration phase than at the mature industry stage. Thus, constructing demonstration plants in proximity to population centers may increase public opposition to synthetic fuels commercialization (see also Section 3.3).

As shown in Table 4-2, public perceptions regarding the severity of environmental and human health impacts from synthetic fuels show a considerable range. For example, some groups believe that large emissions of air pollutants from these plants will degrade the quality of air and damage crop yields. At the other extreme, some believe that air quality will be relatively unaffected by the plant. Similarly, public perceptions of water quality impacts range from the very optimistic (assuming zero discharge of pollutants) to very pessimistic (discharges will cause fish kills and overall degradation of water quality). For water availability, the differences in perspective stem in large part from controversy over the extent and the appropriate use of existing water supplies. Another issue is concern over the potential human health risks from the synthetic fuels industry. Although some groups are worried about the carcinogenic effects of synfuel development, others

TABLE 4-2: RANGE OF PUBLIC PERCEPTIONS OF SYNTHETIC FUELS INDUSTRY

Pessimistic or Opponents of Development		Optimistic or Proponents of Development	
Perception	Source	Perception	Source
Air			
Air quality will be degraded and be unpleasant	U.S., DOE 1981b Robbins 1980	Air quality will be largely unaffected	U.S., DOE 1981b
Air pollution will severely affect agriculture	Parfit 1980		
Water			
Water pollution will result in fish kills and degradation of water quality	U.S., DOE 1981b	Zero discharge of pollutants will eliminate water pollution	U.S., DOE 1981b U.S., EPA 1979
Water consumption will seriously affect existing water users in arid areas (e.g., western Colorado)		Plenty of water is available for all projected synthetic fuel development	U.S., GAO 1979
Health			
Carcinogens threat will make areas undesirable or uninhabitable	U.S., DOE 1981b	Health is protected by EPA, OSHA, and industry activities	U.S., DOE 1981b

believe that industry controls as well as regulations by the Occupational Safety and Health Administration and EPA will provide adequate protection.

The extent of these differences in public perceptions may be narrowed if better information about the likely impacts of coal liquefaction is provided. Most information on coal liquefaction is restricted to technical literature; thus, it may be important to disseminate it in other forms to a larger public. Just as important is the need for information to be generated by groups which have some credibility with the public. Studies should be conducted by individuals and groups who are perceived as competent and have no stake in the industry's development (Section 4.4). Better quality and use of information, of course, does not mean that conflicting public perceptions will be resolved. However, it can provide a focus for policy conflicts and narrow the range of disagreement.

4.4 ENVIRONMENTAL RESEARCH PROGRAMS

The environmental research programs for coal liquefaction are planned and sponsored largely by the U.S. Environmental Protection Agency (U.S., ORD, DEMI, EPA 1979; U.S., EPA, IERL 1980) and by the Office of Environment in the U.S. Department of Energy (U.S., DOE, Asst. Sec. for Fossil Energy and Asst. Sec. for Environment 1980). Other branches of government (e.g., the National Institute of Occupational Safety and Health) in coordination with these two lead agencies and private research programs (such as those sponsored by the Electric Power Research Institute) also have active research programs to characterize environmental and health risks (Males 1980). However, several deficiencies in the existing research program can be identified. These inadequacies are of three types:

- Gaps in technical research programs;
- Gaps in social impact and policy research; and
- Deficiencies in research program organization.

Technical Research Gaps

There are a number of scientific and technical unknowns concerning coal liquefacton that have been identified throughout this report. While most of these questions cannot be resolved until demonstration or pioneer commercial plants are operated, others could be, but are not being, addressed now. Table 4-3 identifies some of these important information gaps. For example, although development programs have been initiated for refining and upgrading coal liquids, with the exception of tests on combustion in stationary sources, little effort has been made to environmentally test coal derived liquids or liquid mixtures used for transportation purposes. A review of health and environmental research programs, especially related to risks from upsets or emergencies and product end-use, is needed to determine whether they are adequate to provide timely information if synfuels are commercialized.

Social and Policy Research Gaps

Most of the current research on synthetic fuels focuses on the physical characteristics of the technologies and the physical/biological effects of their pollutants. However, of potentially

TABLE 4-3: SELECTED TECHNICAL INFORMATION GAPS

Area	Concern	Problem	Implications
Products: Light and medium weight liquids toxicity	Presence of benzene, and other trace chemicals	These chemicals are known to cause leukemia and induce liver tumors. Current research focuses on skin cancer and bacterial mutagenesis.	Composition of products known but environmental significance ambiguous. Indicates need for wider range of carcinogen testing methods.
Process Emissions: Emissions of "reduced" sulfur compounds	Hydrogen sulfide, carbonyl sulfide, carbon disulfide	Neurotoxic agents in low concentrations; implicated in reproductive disorders	Emission and exposure levels expected to be low, but problem potentially important from fugitive or accidental emissions.
Safety system: Controlled combustion systems	Little data available on actual design. Toxic mixture will be introduced into the system.	Failure in performance of controlled combustor could result in intermittent releases of toxic compounds.	Alternative design choices, performance criteria and testing and monitoring procedures need to be developed.
End use: Gasoline and Diesel fuel use	Particulate, nitrogen and sulfur emissions; effects on catalytic converters	Fractions of coal derived naphtha mixtures in product markets is uncertain; environmental impact uncertain and untested.	Better environmental information on fuel characteristics and end-uses needs to be developed.

equal importance are "softer" research needs that address the social impacts of a major synfuels program and the policy of institutional mechanisms that influence, or can be used to influence, environmental choices. Examples of research questions in this area are:

(1) What are the current public attitudes and concerns and how are they being addressed by the synfuels demonstration program?

(2) What is the range of potential changes in public attitudes toward regulation and how might these changes affect synfuel development?

(3) What factors will influence the choices of technology, location, and rate of synfuel development, and how will these influence short- and long-term environmental impacts?

(4) Have siting laws or other institutional factors made a significant effect on where facility sites are planned? How have institutional factors affected social, economic, and environmental trade-offs?

Research Program Organization

As identified in the previous section, there is widespread but divergent public concern with the environmental and human health risks associated with synfuel development. While the widely divergent opinions may not ever be completely resolvable, the situation could be improved with more reliable and credible impact information. This requires that research and monitoring programs not only be scientifically and technically sound, but also:

- The research program must involve a diversity of interests in its planning and its review;
- Impact assessments must include site-specific components to directly inform those who may be affected;
- The studies must be funded and carried out by parties who do not have a vested interest in the technology.

Many of the current research programs do not meet these criteria. For example, biomedical research on the carcinogenity of synthetic fuels mixtures is primarily sponsored by the DOE and conducted through its national laboratories, which are viewed by some groups as proponents of synthetic fuel development.

5.0 WHAT ARE THE ENVIRONMENTAL RISKS OF AN ACCELERATED SYNFUELS COMMERCIALIZATION PROGRAM?

Although the technology for producing liquid fuels from coal was first demonstrated by Germany during the 1920's, coal liquefaction is still in an early state of development in this country; no commercial-scale plants exist or are under construction in the U.S. A "crash" or "accelerated" commercialization program to reduce dependence on foreign oil will involve substantial technical, economic, and environmental risks.

Indirect coal liquefaction is closer to commercialization than direct processes. However, rapid deployment of indirect processes will require the use of currently commercial gasifiers such as Lurgi and Koppers-Totzek. More advanced technologies such as the Texaco coal gasifier and the pressurized Shell-Koppers and Winkler gasifiers are not yet in advanced pilot plant stages and need to go through the commercial module demonstration stage before commercialization.

Figure 5-1 illustrates the time required for the development of a commercial plant for two direct processes, EDS and H-Coal, under a "normal" development schedule as projected by the licensing firm (developers). Development is estimated to take 17 years for the

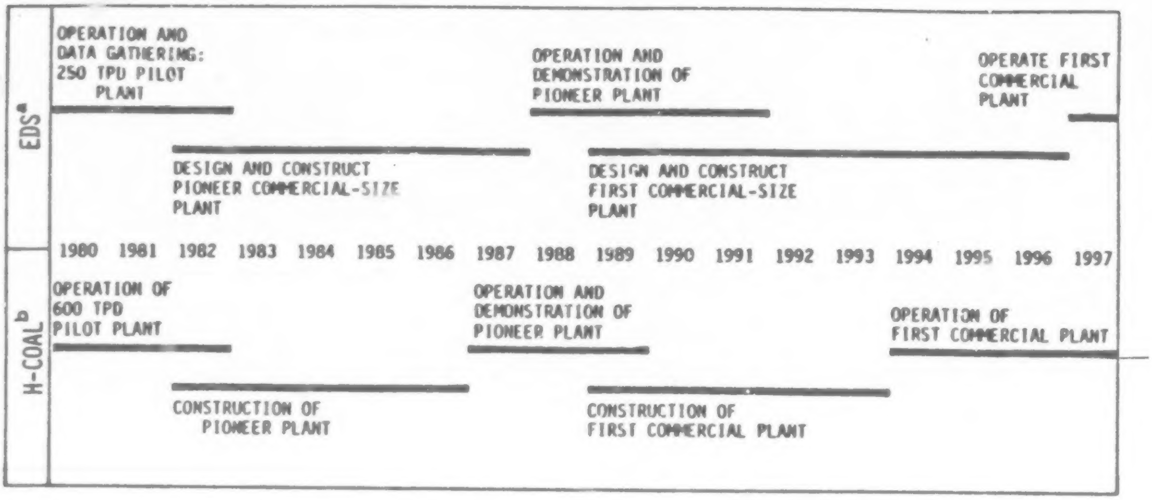


Figure 5-1: Time schedule for two direct coal liquefaction processes.

[a] Green 1980.

[b] Based on two years operation before construction of next unit, design and construction five-year time estimate from Rogers and Hill 1979.

Exxon Donor Solvent (EDS) process and 14 years for the H-Coal process. The EDS estimate includes 7 years for design and construction following operation of both a 250 tpd pilot plant and a pioneer commercial size unit. In contrast, it is estimated that the H-Coal process will require only a 5-year construction period; all design presumably takes place while gathering data from operating units. These estimates have assumed that the permitting process goes on concurrently with design. Because designing requires several years, it is the primary determinant in project schedules. However, if permitting is not concurrent, then an increase equivalent to permitting time for each step would be added to the timetables.

If coal synfuels are commercialized rapidly, it would require: (1) deploying indirect processes now utilizing Lurgi or Kopper-Totzek gasification and/or (2) by-passing some of the scale-up steps in the development of the newer gasification or direct process technologies. Both approaches, and especially the latter, may be unwise for technical and economic reasons. In addition, accelerated commercialization programs will contribute to increased environmental risks for four reasons:

- Technical risks from by-passing development steps;
- Difficulty in monitoring and detecting impacts;
- Regulatory lags; and
- Added impacts from rapid construction.

Each of these factors is briefly discussed below.

5.1 RISKS DUE TO TECHNICAL UNCERTAINTIES

The technical uncertainties in commercial plant performance have typically resulted in requirements for a bench-scale, pilot plant, pioneer plant, and commercial-scale plant development sequence. In the case of direct processes (see Section 2), this scale-up sequence is required primarily because of the inability to predict the flow of coal solids, semisolids, and entrained solids in a liquefaction plant. Thus, they must be tested for phases in a scale-up to commercial size. Any increase in the frequency of upsets or accidents (see Section 2.2) due to accelerated development programs could cause a major increase in air emissions and occupational health and safety risks. In the case of air emissions, neither the controlled combuster nor the vent/flare systems are designed with sulfur or particulate removal systems; therefore, upsets from plugging, reactor malfunctioning, and other events can lead to major increases in emissions of some pollutants. These technical problems can also increase risks of leaks, explosions, and other plant accidents. Further, if units are improperly designed, risks in a complex plant are not simply additive. For example, a poorly designed section that plugs can result in other sections of a facility being shut down. These shut-downs result in temperature changes that can cause stress in valves and fittings, further contributing to leaks or other failures.

Water quality impacts are also of concern with accelerated development because wastewater treatment designs are just emerging. Materials balances and performance data based on preliminary designs are not available. The wastewater treatment systems have not been tested against actual plant conditions, since existing small pilot plants now send waste streams to adjacent refineries. Performance data from wastewater treatment systems being designed for pioneer plants need to be evaluated prior to full-scale commercialization. Because of this uncertainty and the potential for failure in the wastewater treatment system, for example due to poisoning of biotreaters, the water quality risks would be increased under an accelerated schedule.

Generally, strong economic incentives exist for adequate design and testing in order to achieve a high level of plant operation capacity. Thus, developers are typically wary of a rapid development schedule for economic reasons. However, as discussed in Section 4.2, the environmental costs can sometimes be much larger than the economic costs if a plant does not perform properly. For example, fugitive emissions of toxic hydrocarbons may represent a substantial health risk, but they may only represent a small economic cost in terms of lost product. For this reason, accelerated development programs should include rigorous environmental monitoring programs.

5.2 DIFFICULTIES IN MONITORING

As discussed in Section 4.1, several of the potential environmental impacts associated with coal synfuels will be difficult to monitor and detect. This problem will exist even under a "normal" development pace (such as that illustrated in Figure 5-1), and it will be exacerbated by rapid commercialization programs. Rapid commercialization would limit data development and interpretation from monitoring programs. For example, the latency of skin cancer can be 5 to 10 or more years after exposure, with other cancers having an even longer latency. Rapid commercialization programs would increase the risks that environmental hazards would be overlooked during the first years of pilot or pioneer plant operation.

A "normal" development schedule, such as described in Section 5.0, can resolve a range of existing health uncertainties as summarized in Table 5-1. Pilot plant operation provides time for screening the range of products for bacterial mutagenicity, laboratory carcinogenicity tests, and toxicology studies. The

TABLE 5-1: HEALTH RISKS POTENTIALLY RESOLVED DURING A NORMAL DEVELOPMENT SCHEDULE

		Uncertainties Potentially Resolved	
Plant Stage	Time Duration (years)	Emissions/ Effluents/Products	Health Risk
Pilot plant operation	1-4	Product composition	Bacterial mutagenicity Short-term laboratory carcinogenicity
Constructing pioneer plant	3-8	None	None
Demonstration of pioneer plant	8-14	Composition of discharge streams (preliminary)	Initial worker accident risk assessed Potential public exposure determined
Construction of first commercial plant	12-15	None	None
Commercial plant operation	15-30	Composition of discharge streams	Levels of public exposure confirmed (commercial)
		Quantity of discharges	Longer term worker and and accident risks informed
Long term operation and retirement	30-55	Quantity of discharges; leaks; hazards assessment	Worker accident risk confirmed Actual public health risk informed
Decomissioning	55-	None	Public and occupational health risk more conclusively informed

demonstration (pioneer) plant phase provides for an evaluation of the composition of discharge streams, for determination of potential public exposure to chemicals, and an initial evaluation of occupational accident and exposure risks. A normal development sequence can provide for some determination of all but the long term risks, such as those due to cancer, prior to the operation of a commercial plant.

Although a range of short-term screening tests can be used to evaluate the hazards of intermediate process streams, discharges, and products, some hazard will remain that can only be evaluated with detailed occupational and public health studies. As indicated above, these studies are likely to identify risk (for some skin cancers) within as few as about 5 years. As indicated in the examples in Table 5-2 some cancers show up sooner than five years, such as those induced by chemical therapy or ionizing radiation. However, cancers initiated by occupational exposures to various chemicals, such as detection of elevated rates of lung and kidney cancer from exposure to chemicals in coal tar, typically require 10 to 20 or more years to be detected. Because the latency period of cancer is dependent on the organ, dose, and susceptibilty of the population, no clear pattern emerges to dictate how effective a monitoring program can be over the short term. Apparently many of the risks can be determined within 5 to 10 years of the operation of a pioneer plant, but the degree of risk for many soft tissue cancers can only be determined after up to 30 or more years of commercial plant operation.

TABLE 5-2: TYPICAL LATENCY PERIODS IN CANCER DETECTION

Latency Period (years)	Cause	Cancer (site)
(0.2 to 0.3)	Chemical therapy	Lymphoma (lymph glands)
2 to 15	Ionizing radiation	Leukemia (blood)
5 to 10	PNAS	Skin cancer
10-	Mustard gas	Lung cancer
10 to 15	Vinyl chloride	Liver cancer
10 to 30	Smoking	Lung cancer
10 to 30	Ionizing radiation	Breast cancer
20 to 40	Coal tar	Lung and kidney cancer
35 to 50	Asbestos	Mesothelioma (chest or stomach lining)
up to 60	Burns	Skin cancer

Source: Compiled from National Cancer Institute 1981; Braunstein, Copenhaver and Pfuderer 1978; NIOSH 1977.

5.3 REGULATORY LAG

A closely related problem is regulatory lags that would occur during an accelerated development schedule. As indicated in Section 2.0, emission and discharge standards do not exist for coal liquefaction plants. EPA and DOE are developing "Pollution Control Guidance Documents" (PCGD's) which will serve as guidelines for evaluating plant designs in the near future. Final standards will be an on-going process as more is learned from each new pilot or pioneer commercial plant. If a synfuels commercialization program is accelerated by building the next generation of plants before fully evaluating the previous one, or by simply by-passing steps in the normal scale of sequence, then some types of environmental regulations (such as emission standards) would always lag behind ongoing design and construction. Experience with the nuclear power industry has shown the problems of attempting to redesign components of a very complex system in response to environmental/safety concerns while the project is under construction. Accelerated development increases environmental risks because each generation of plants would not be guided by environmental regulations informed by the prior generation, and any modifications or retrofits needed to correct past deficiencies would often be very expensive.

5.4 IMPACTS FROM RAPID CONSTRUCTION

Accelerated development of synfuels could also aggravate the socioeconomic and environmental problems associated with "boom and bust" population cycles in small communities. These problems include:

- Inadequate municipal services (water supply, police and fire protection, etc.);
- Insufficient housing;
- Water quality and ecological effects (e.g., inadequate sewage treatment capacity); and
- Inadequate streets, roads, and highways.

Although these growth management problems will exist for any large construction project in rural areas, they will be increased by an accelerated synfuels program because of the number of plants required, the lack of means to coordinate plant schedules, and the probability that many facilities will be located in clusters in single or multicounty regions in the eastern U.S. (for example, see Enoch 1980). As an example, Figure 5-2 shows the number of workers included in synfuel plant construction in a 30-mile radius of Owensboro, Kentucky, if plans developed in 1980 should be implemented.

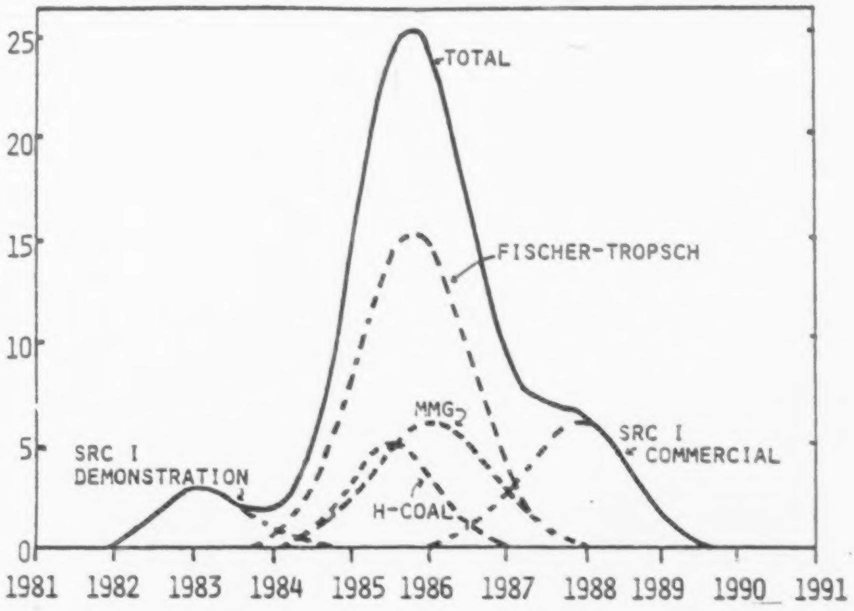
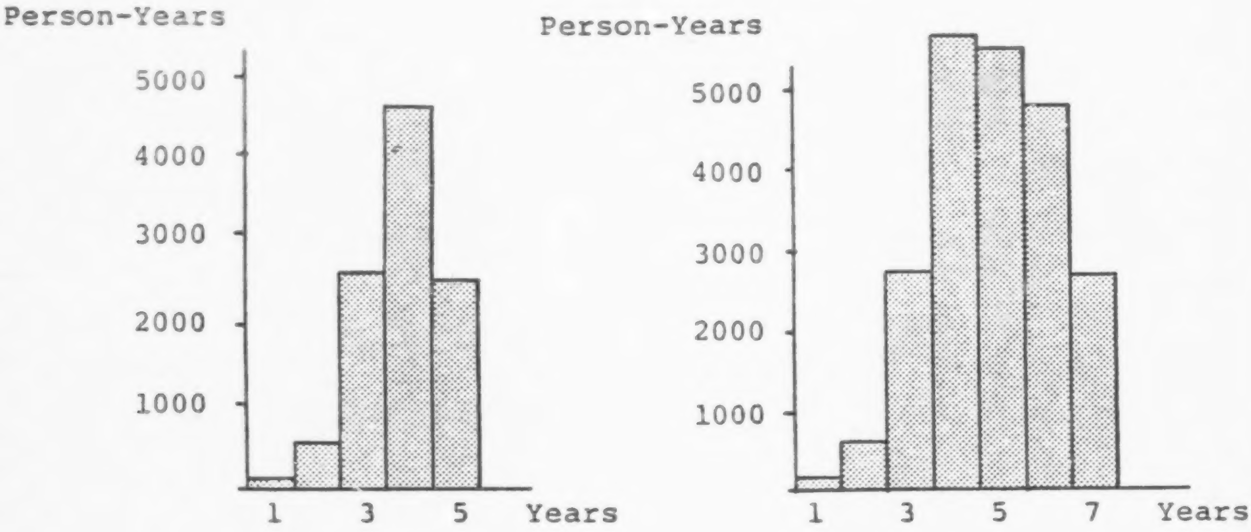


Figure 5-2: Synfuel plant construction labor requirement near Owensboro, Kentucky.

Source: Enoch 1980.

Scheduling can play a major role in determining the magnitude of population impacts experienced by a community. Construction of a coal synfuel plant can require a peak workforce of approximately 5,000; this can result in population increases of 15,000, including family members and secondary population growth. Figure 5-3(A) illustrates a typical workforce schedule for a coal gasification plant. Simultaneous construction of two or more plants in an area under an accelerated synfuels commercialization program will proportionately increase population and probably exponentially increase impacts. On the other hand, construction of multiple plants can be phased so that population impacts are lessened, as illustrated in Figure 5-3(B).



(A) Single Plant

(B) Two plants started 2 years apart

Figure 5-3: Workforce schedules for coal gasification projects. Source: White *et al*. 1979.

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